User’s Manual - NXP / CEA-Leti

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PSP 104.0.0

The PSP model is a joint development of CEA-Leti and NXP Semiconductors

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Abstract: The PSP model is a compact MOSFET model intended for analog, RF, and digital design. It is jointly developed by NXP Semiconductors and CEA-Leti. From 2011 to 2015, it was jointly developed by NXP Semiconductors and Delft University of Technology. Until 2011, it was jointly developed by NXP Semiconductors and Arizona State University. The roots of PSP lie in both *MOS Model 11* (developed by NXP Semiconductors) and *SP* (developed at the Pennsylvania State University and later at Arizona State University). PSP is a surface-potential based MOS Model, containing all relevant physical effects (mobility reduction, velocity saturation, DIBL, gate current, lateral doping gradient effects, STI stress, etc.) to model present-day and upcoming deep-submicron bulk CMOS technologies. The source/drain junction model, c.q. the JUNCAP2 model, is fully integrated in PSP. This report contains a full description of the PSP model, including parameter sets, scaling rules, model equations, and a description of the parameter extraction procedure.
In December 2005, the Compact Model Council (CMC) has elected PSP as the new industrial standard model for compact MOSFET modeling.
Since December 2015, CEA-Leti replaces Delft University of Technology as the supporting institution.

Silicon Integration Initiative (Si2) - Compact Model Coalition In-Code Statement

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Section 1

Introduction

1.1 Origin and purpose

The PSP model is a compact MOSFET model intended for analog, RF, and digital design. It is jointly developed by NXP Semiconductors and CEA-Leti. (From 2011 until 2015, it was jointly developed by NXP Semiconductors and Delft University of Technology. Until 2011, it was jointly developed by NXP Semiconductors and Arizona State University. The roots of PSP lie in both *MOS Model 11* (developed by NXP Semiconductors) and *SP* (developed at the Pennsylvania State University and later at Arizona State University). PSP is a surface-potential based MOS Model, containing all relevant physical effects (mobility reduction, velocity saturation, DIBL, gate current, lateral doping gradient effects, STI stress, etc.) to model present-day and upcoming deep-submicron bulk CMOS technologies. The source/drain junction model, c.q. the JUNCAP2 model, is fully integrated in PSP.

PSP not only gives an accurate description of currents, charges, and their first order derivatives (i.e. transconductance, conductance and capacitances), but also of the higher order derivatives, resulting in an accurate description of electrical distortion behavior. The latter is especially important for analog and RF circuit design. The model furthermore gives an accurate description of the noise behavior of MOSFETs. Finally, PSP has an option for simulation of non-quasi-static (NQS) effects.

The source code of PSP and the most recent version of this documentation are available on the PSP model web site: `http://www.cea.fr/cea-tech/leti/pspsupport` and the NXP Semiconductors web site: `www.nxp.com/models`.

1.2 Structure of PSP

The PSP model has a hierarchical structure, similar to that of MOS Model 11 and SP. This means that there is a strict separation of the geometry scaling in the global model and the model equations in the local model.

As a consequence, PSP can be used at either one of two levels.

- **Global level** One uses a global parameter set, which describes a whole geometry range. Combined with instance parameters (such as L and W), a local parameter set is internally generated and further processed at the local level in exactly the same way as a custom-made local parameter set.
- **Local level** One uses a custom-made local parameter set to simulate a transistor with a specific geometry. Temperature scaling is included at this level.

The set of parameters which occur in the equations for the various electrical quantities is called the *local* parameter set. In PSP, temperature scaling parameters are included in the local parameter set. An overview of the local parameters in PSP is given in Section 2.5.2. Each of these parameters can be determined by purely electrical measurements. As a consequence, a local parameter set gives a complete description of the electrical properties of a device of *one* particular geometry.

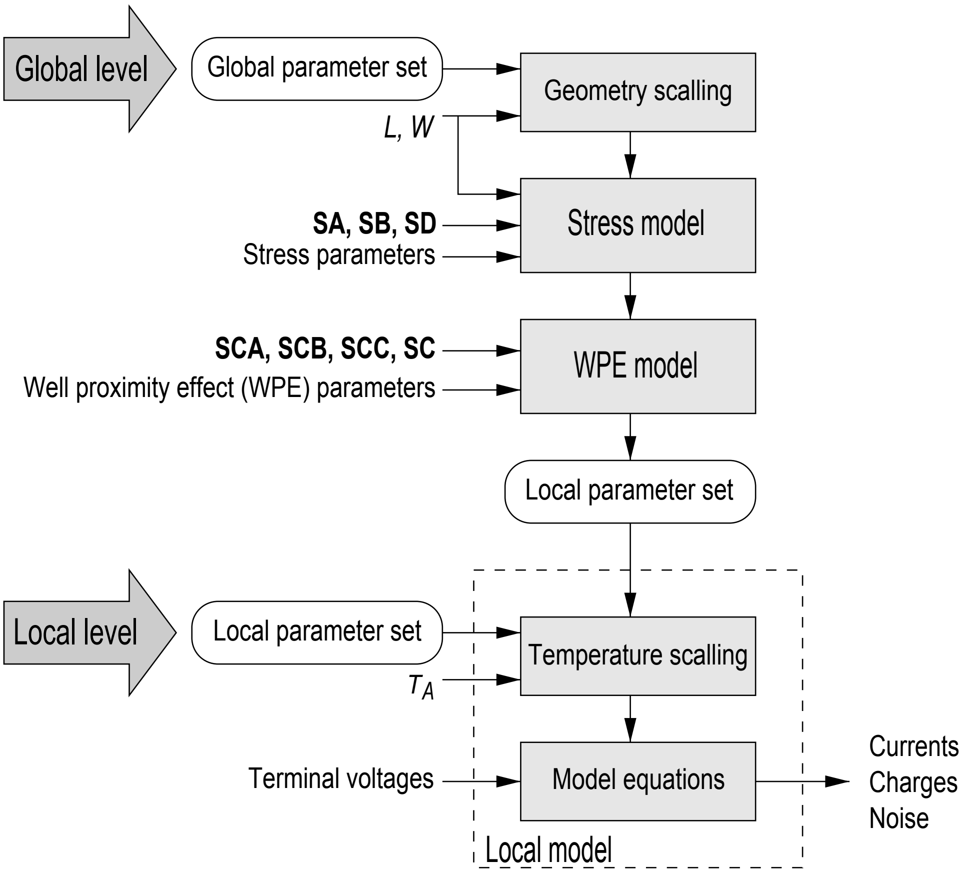

Figure 1.1: Simplified schematic overview of PSP's hierarchical structure.

Since most of these (local) parameters scale with geometry, all transistors of a particular process can be described by a (larger) set of parameters, called the *global* parameter set. An overview of the global parameters in PSP is given in Section 2.5.2. Roughly speaking, this set contains all local parameters for a long/wide device plus a number of sensitivity coefficients. From the global parameter set, one can obtain a local parameter set for a specific device by applying a set of scaling rules (see Section 3.3). The geometric properties of that specific device (such as its length and width) enter these scaling rules as *instance parameters*.

From PSP 101.0 onwards it is possible to use a set of binning rules (see Section 3.4) as an alternative to the geometrical (physics based) scaling rules. These binning rules come with their own set of parameters (see Section 2.5.2). Similar to the geometrical scaling rules, the binning rules yield a local parameter set which is used as input for the local model.

PSP is preferably used at global level when designing a circuit in a specific technology for which a global parameter set is available. On the other hand, using PSP at local level can be advantageous during parameter extraction.

As an option, it is possible to deal with the modifications of transistor properties due to stress and well proximity effect (WPE). In PSP, this is implemented by additional sets of transformation rules, which are optionally applied to the intermediate local parameter set generated at the global level. The parameters associated with the stress and WPE models are consequently part of the global parameter set (both geometrical and binning).

The model structure described above is schematically depicted in Fig. 1.1.

The JUNCAP2 model is implemented in such a way that the same set of JUNCAP2 parameters can be used at both the global and the local level. This is further explained in Section 6.4.

1.3 Availability

The PSP model developers (CEA-Leti and NXP Semiconductors) distribute the PSP code in two formats:

1. Verilog-A code
2. C-code (as part of SiMKit-library)

The C-version is automatically generated from the Verilog-A version by the software package ADMS [1]. This procedure guarantees the two implementations to contain identical equations. Nevertheless—due to some specific limitations/capabilities of the two formats—there are a few minor differences, which are described in Section 6.5.

1.3.1 SiMKit

SiMKit is a simulator-independent compact transistor model library. Simulator-specific connections are handled through so-called adapters that provide the correct interfacing to the circuit simulator of choice. Currently, adapters to the following circuit simulators are provided:

1. Spectre (Cadence)
2. Pstar (NXP Semiconductors)
3. ADS (Agilent)

Some other circuit simulators vendors provide their own SiMKit adapter, such that simulations with models in SiMKit are possible.

Section 2

Constants and Parameters

2.1 Nomenclature

The nomenclature of the quantities listed in the following sections has been chosen to express their purpose and their relation to other quantities and to preclude ambiguity and inconsistency. Throughout this document, all PSP parameter names are printed in boldface capitals. Parameters which refer to the long transistor limit and/or the reference temperature have a name containing an '**O**', while the names of scaling parameters end with the letter '**L**' and/or '**W**' for length or width scaling, respectively. Parameters for temperature scaling start with '**ST**' or '**ST2**', followed by the name of the parameter to which the temperature scaling applies. Parameters used for the binning model start with '**PO**', '**PL**', '**PW**', or '**PLW**', followed by the name of the local parameter they refer to.

2.2 Parameter clipping

For most parameters, a maximum and/or minimum value is given in the tables below. In PSP, all parameters are limited (clipped) to this pre-specified range in order to prevent difficulties in the numerical evaluation of the model, such as division by zero.

N.B. After computation of the scaling rules (either physical and/or binning), stress and well proximity effect equations, the resulting local parameters are subjected to the clipping values as given in Section 2.5.2.

2.3 Circuit simulator variables

External electrical variables

The definitions of the external electrical variables are illustrated in Fig. 2.1. The relationship between these external variables and the internal variables used in Chapter 4 is given in Fig. 6.1.

Symbol	Unit	Description
V_D^e	V	Potential applied to drain node
V_G^e	V	Potential applied to gate node
V_S^e	V	Potential applied to source node
V_B^e	V	Potential applied to bulk node
I_D^e	A	DC current into drain node

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Symbol	Unit	Description
I^e_{G}	A	DC current into gate node
I^e_{S}	A	DC current into source node
I^e_{B}	A	DC current into bulk node
S^e_{fl}	$\mathrm{A^2 s}$	Spectral density of flicker noise current in the channel
$S^e_{\mathrm{fl,edge}}$	$\mathrm{A^2 s}$	Spectral density of flicker noise current of edge transistor
S^e_{id}	$\mathrm{A^2 s}$	Spectral density of thermal noise current in the channel
$S^e_{\mathrm{id,edge}}$	$\mathrm{A^2 s}$	Spectral density of thermal noise current of edge transistor
$S^e_{\mathrm{ig,S}}$	$\mathrm{A^2 s}$	Spectral density of induced gate noise at source side
$S^e_{\mathrm{ig,D}}$	$\mathrm{A^2 s}$	Spectral density of induced gate noise at drain side
S^e_{igs}	$\mathrm{A^2 s}$	Spectral density of gate current shot noise at source side
S^e_{igd}	$\mathrm{A^2 s}$	Spectral density of gate current shot noise at drain side
$S^e_{\mathrm{j,S}}$	$\mathrm{A^2 s}$	Spectral density of source junction shot noise
$S^e_{\mathrm{j,D}}$	$\mathrm{A^2 s}$	Spectral density of drain junction shot noise
S^e_{igid}	$\mathrm{A^2 s}$	Cross spectral density between S^e_{id} and (S^e_{igS} or S^e_{igD})

Other circuit simulator variables

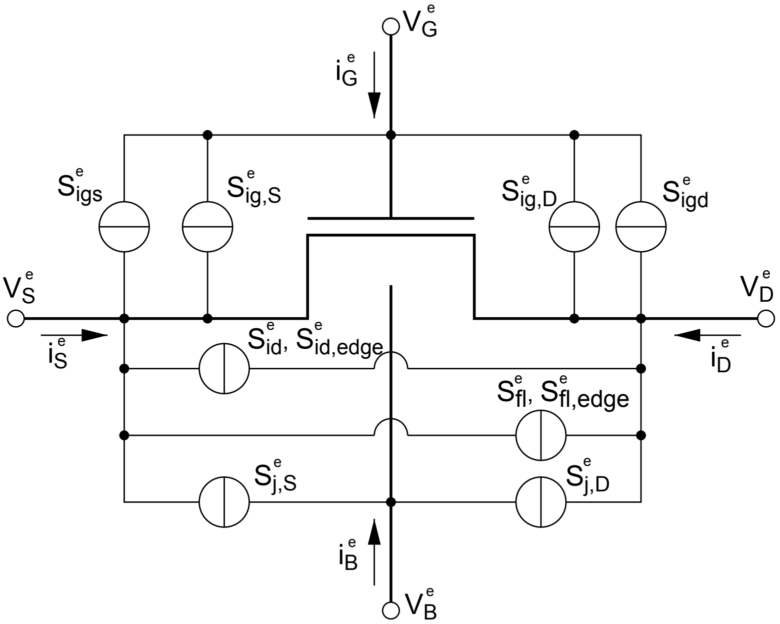
Next to the electrical variables described above, the quantities in the table below are also provided to the model by the circuit simulator.

Symbol	Unit	Description
T_{A}	°C	Ambient circuit temperature
f_{op}	Hz	Operation frequency

2.4 Model constants

In the following table the symbolic representation, the value and the description of the various physical constants used in the PSP model are given.

No.	Symbol	Unit	Value	Description
1	T_0	K	273.15	Offset between Celsius and Kelvin temperature scale
2	k_{B}	J/K	$1.3806505 \cdot 10^{-23}$	Boltzmann constant
3	$\hbar$	J s	$1.05457168 \cdot 10^{-34}$	Reduced Planck constant
4	q	C	$1.6021918 \cdot 10^{-19}$	Elementary unit charge
5	m_0	kg	$9.1093826 \cdot 10^{-31}$	Electron rest mass
6	ϵ_0	F/m	$8.8541878176 \cdot 10^{-12}$	Permittivity of free space
7	$\epsilon_{\mathrm{r,Si}}$	–	11.8	Relative permittivity of silicon
8	QM_{N}	$\mathrm{V\,m^{\frac{4}{3}}C^{-\frac{2}{3}}}$	5.951993	Constant of quantum-mechanical behavior of electrons
9	QM_{P}	$\mathrm{V\,m^{\frac{4}{3}}C^{-\frac{2}{3}}}$	7.448711	Constant of quantum-mechanical behavior of holes



$$i^e_{\mathrm{D}} = I^e_{\mathrm{D}} + \frac{\mathrm{d}Q^e_{\mathrm{D}}}{\mathrm{d}t}$$

$$i^e_{\mathrm{G}} = I^e_{\mathrm{G}} + \frac{\mathrm{d}Q^e_{\mathrm{G}}}{\mathrm{d}t}$$

$$i^e_{\mathrm{S}} = I^e_{\mathrm{S}} + \frac{\mathrm{d}Q^e_{\mathrm{S}}}{\mathrm{d}t}$$

$$i^e_{\mathrm{B}} = I^e_{\mathrm{B}} + \frac{\mathrm{d}Q^e_{\mathrm{B}}}{\mathrm{d}t}$$

Figure 2.1: Definition of external electrical quantities.

2.5 Model parameters

In this section all parameters of the PSP-model are described. The parameters for the intrinsic MOS model, the stress and well proximity effect models and the junction model are given in separate tables. The complete parameter list for each of the model entry levels is composed of several parts, as indicated in the table below.

Entry level	Sections
Global (physical scaling and binning)	2.5.1 (instance parameters)
	2.5.2 (intrinsic MOS)
	2.5.5 (stress)
	2.5.6 (well proximity effect)
	2.5.7 (junctions)
	2.5.8 (parasitic resistances)
Local	2.5.1 (instance parameters)
	2.5.2 (intrinsic MOS)
	2.5.7 (junctions)
	2.5.8 (parasitic resistances)

2.5.1 Instance parameters

The instant parameters for global, local and binning models are listed in the table below. The last column of **Geo.** shows for which value of **SWGEO** the listed parameter is used. Note that, as explained in Section 6.4, the instance parameters for the JUNCAP2 model are used at the local level as well.

No.	Name	Unit	Default	Min.	Max.	Description	Geo.
0	L	m	10^{-6}	10^{-9}	–	Drawn channel length	1

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
1	W	m	10^{-6}	10^{-9}	–	Drawn channel width (total width)	1
2	**ABSOURCE**	m^2	10^{-12}	0	–	Source junction area	0, 1
3	**LSSOURCE**	m	10^{-6}	0	–	STI-edge part of source junction perimeter	0, 1
4	**LGSOURCE**	m	10^{-6}	0	–	Gate-edge part of source junction perimeter	0, 1
5	**ABDRAIN**	m^2	10^{-12}	0	–	Drain junction area	0, 1
6	**LSDRAIN**	m	10^{-6}	0	–	STI-edge part of drain junction perimeter	0, 1
7	**LGDRAIN**	m	10^{-6}	0	–	Gate-edge part of drain junction perimeter	0, 1
8	**AS**	m^2	10^{-12}	0	–	Source junction area (alternative spec.)	0, 1
9	**PS**	m	10^{-6}	0	–	Source STI-edge perimeter (alternative spec.)	0, 1
10	**AD**	m^2	10^{-12}	0	–	Drain junction area (alternative spec.)	0, 1
11	**PD**	m	10^{-6}	0	–	Drain STI-edge perimeter (alternative spec.)	0, 1
12	**JW**	m	10^{-6}	0	–	Junction width	0
13	**DELVTO**	V	0	–	–	Threshold voltage shift parameter	0, 1
14	**FACTUO**	–	1	0	–	Zero-field mobility pre-factor	0, 1
15	**DELVTOEDGE**	V	0	–	–	Threshold voltage shift parameter of edge transistor	0, 1
16	**FACTUOEDGE**	–	1	0	–	Zero-field mobility pre-factor of edge transistor	0, 1
17	**SA**	m	0	–	–	Distance between OD-edge and poly at source side	1
18	**SB**	m	0	–	–	Distance between OD-edge and poly at drain side	1
19	**SD**	m	0	–	–	Distance between neighboring fingers	1
20	**SCA**	–	0	0	–	Integral of the first distribution function for scattered well dopant	1
21	**SCB**	–	0	0	–	Integral of the second distribution function for scattered well dopant	1
22	**SCC**	–	0	0	–	Integral of the third distribution function for scattered well dopant	1
23	**SC**	m	0	–	–	Distance between OD edge and nearest well edge	1
24	**NRS**	–	0	–	–	Number of squares of source diffusion	1
25	**NRD**	–	0	–	–	Number of squares of drain diffusion	1
26	**NGCON**	–	1	1	2	Number of gate contacts	1
27	**XGW**	m	10^{-7}	–	–	Distance from the gate contact to the channel edge	1

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
28	**NF**	–	1	1	–	Number of fingers; internally rounded to the nearest integer	1
29	**MULT**	–	1	0	–	Number of devices in parallel	0, 1
30	**TRISE or DTEMP**	K	0	–	–	Device temperature offset	0, 1

Note that if both **SA** and **SB** are set to 0 the stress-equations are not computed. If **SCA**, **SCB**, **SCC** and **SC** are all set to 0 the well proximity effect equations are not computed.

The switching parameter **SWJUNCAP** is used to determine the meaning and usage of the junction instance parameters, where **AB** (junction area), **LS** (STI-edge part of junction perimeter), and **LG** (gate-edge part of junction perimeter) are the instance parameters of a single instance (source or drain) of the JUNCAP2 model.

	source			drain		
SWJUNCAP	**AB**	**LS**	**LG**	**AB**	**LS**	**LG**
0	0	0	0	0	0	0
1	**ABSOURCE**	**LSSOURCE**	**LGSOURCE**	**ABDRAIN**	**LSDRAIN**	**LGDRAIN**
2	**AS**	**PS**	W_{E}	**AD**	**PD**	W_{E}
3	**AS**	**PS** $-\ W_{\mathrm{E}}$	W_{E}	**AD**	**PD** $-\ W_{\mathrm{E}}$	W_{E}

At the local level, the switching parameter **SWJUNCAP** is used to determine the meaning and usage of the junction instance parameters, where **AB** (junction area), **LS** (STI-edge part of junction perimeter), and **LG** (gate-edge part of junction perimeter) are the instance parameters of a single instance (source or drain) of the JUNCAP2 model. Because the transistor width W is not available at the local level, an additional instance parameter **JW** (junction width) is required when **SWJUNCAP** $= 2$ or 3.

	source			drain		
SWJUNCAP	**AB**	**LS**	**LG**	**AB**	**LS**	**LG**
0	0	0	0	0	0	0
1	**ABSOURCE**	**LSSOURCE**	**LGSOURCE**	**ABDRAIN**	**LSDRAIN**	**LGDRAIN**
2	**AS**	**PS**	**JW**	**AD**	**PD**	**JW**
3	**AS**	**PS** – **JW**	**JW**	**AD**	**PD** – **JW**	**JW**

2.5.2 Intrinsic model

The model parameters for the intrinsic part of the MOSFET are listed in the table below. The last column—labeled ‘**Geo.**’—shows for which value of **SWGEO** the parameter is used. The convention used in this table is that, if a scaling rule exists for a local parameter its scaling (global and/or binning) parameters are grouped underneath. Note also some parameters do not have their local counterparts.

No.	Name	Unit	Default	Min.	Max.	Description	Geo.
0	**LEVEL**	–	104	–	–	Model selection parameter; see Sec. 6.1	0, 1
1	**TYPE**	–	1	-1	1	Channel type parameter; 1 ↔ NMOS, -1 ↔ PMOS[1]	0, 1
2	**TR or TREF**	°C	21	-273	–	Reference temperature	0, 1
3	**DTA**	K	0	–	–	Temperature offset w.r.t. ambient circuit temperature	0, 1
				Switches			
4	**PARAMCHK**	–	0	–	–	Level of clip-warning info[2]	0, 1
5	**SWGEO**	–	1	0	1	Flag for geometrical model (0 ↔ local, 1 ↔ globa and/or binning)	0, 1
6	**SWIGATE**	–	0	0	1	Flag for gate current (0 ↔ “off”, 1 ↔ “on”)	0, 1
7	**SWIMPACT**	–	0	0	1	Flag for impact ionization current (0 ↔ “off”)	0, 1
8	**SWGIDL**	–	0	0	1	Flag for GIDL/GISL current (0 ↔ “off”)	0, 1
9	**SWJUNCAP**	–	0	0	3	Flag for JUNCAP (0 ↔ “off”)	0, 1
10	**SWJUNASYM**	–	0	0	1	Flag for asymmetric junctions (0 ↔ “off”)	0, 1
11	**SWNUD**	–	0	0	2	Flag for NUD-effect (0 ↔ “off”)	0, 1
12	**SWEDGE**	–	0	0	1	Flag for drain current of edge transistors (0 ↔ “off”)	0, 1
13	**SWDELVTAC**	–	0	0	1	Flag for separate charge calculation (0 ↔ “off”)	0, 1
14	**SWQSAT**	–	0	0	1	Flag for separate charge calculation in saturation (0 ↔ “off”)	0, 1
15	**SWQPART**	–	0	0	1	Flag for drain/source charge partitioning (0 ↔ “linear distribution”, 1 ↔ “source”)	0, 1
16	**QMC**	–	1	0	–	Quantum-mechanical correction factor	0, 1
				Switches for operating point information			
17	**SWOPREXT**	–	0	0	1	Indicates if **RDE**, **RSE** and **RG** are included in OP-output quantities (0 ↔ “not included”, 1 ↔ “included”)	0, 1

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[1] See Section 6.3.1 for more information on usage of **TYPE** in various simulators.

[2] Only in SiMKit-version of PSP. See Section 6.5.4 for more information.

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
18	**SWOPPMOS**	–	0	0	1	Switch for pmos convention (0 ↔ “used the nmos convention”, 1 ↔ “the type of pmos is preserved”)	0, 1
19	**SWOPDRAIN**	–	0	0	1	Switch for drain configuration (0 ↔ “the drain is the electrical node such as Vds is positive (in nmos convention)”, 1 ↔ “the drain is the first terminal”)	0, 1
						Electrical Geometry Parameters	
20	**LVARO**	m	0	–	–	Geometry independent difference between actual and programmed poly-silicon gate length	1
21	**LVARL**	–	0	–	–	Length dependence of ΔL_{PS}	1
22	**LVARW**	–	0	–	–	Width dependence of ΔL_{PS}	1
23	**LAP**	m	0	–	–	Effective channel length reduction per side due to lateral diffusion of source/drain dopant ions	1
24	**WVARO**	m	0	–	–	Geometry independent difference between actual and programmed field-oxide opening	1
25	**WVARL**	–	0	–	–	Length dependence of ΔW_{OD}	1
26	**WVARW**	–	0	–	–	Width dependence of ΔW_{OD}	1
27	**WOT**	m	0	–	–	Effective reduction of channel width per side due to lateral diffusion of channel-stop dopant ions	1
28	**DLQ**	m	0	–	–	Effective channel length offset for CV	1
29	**DWQ**	m	0	–	–	Effective channel width offset for CV	1
						Flat-Band Voltage Parameters	
30	**VFB**	V	-1	–	–	Flat-band voltage at **TR**	0
31	**VFBO**	V	-1	–	–	Geometry-independent part	1
32	**VFBL**	V	0	–	–	Length dependence	1
33	**VFBLEXP**	–	1	–	–	Exponent for length dependence	1
34	**VFBW**	V	0	–	–	Width dependence	1
35	**VFBLW**	V	0	–	–	Area dependence	1
36	**POVFB**	V	-1	–	–	Binning: geom. independent part	1
37	**PLVFB**	V	0	–	–	Binning: length dependence	1
38	**PWVFB**	V	0	–	–	Binning: width dependence	1
39	**PLWVFB**	V	0	–	–	Binning: area dependence	1
40	**STVFB**	V/K	$5 \cdot 10^{-4}$	–	–	Temperature dependence of **VFB**	0
41	**STVFBO**	V/K	$5 \cdot 10^{-4}$	–	–	Geometry-independent part	1

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
42	**STVFBL**	V/K	0	–	–	Length dependence	1
43	**STVFBW**	V/K	0	–	–	Width dependence	1
44	**STVFBLW**	V/K	0	–	–	Area dependence	1
45	**POSTVFB**	V/K	$5 \cdot 10^{-4}$	–	–	Binning: geom. independent part	1
46	**PLSTVFB**	V/K	0	–	–	Binning: length dependence	1
47	**PWSTVFB**	V/K	0	–	–	Binning: width dependence	1
48	**PLWSTVFB**	V/K	0	–	–	Binning: area dependence	1
49	**ST2VFB**	K^{-1}	0	–	–	Quadratic temperature dependence of **VFB**	0
50	**ST2VFBO**	K^{-1}	0	–	–	Geometry-independent parameter	1
				Process Parameters			
51	**TOX**	m	$2 \cdot 10^{-9}$	10^{-10}	–	Gate oxide thickness	0
52	**TOXO**	m	$2 \cdot 10^{-9}$	10^{-10}	–	Geometry-independent parameter	1
53	**EPSROX**	–	3.9	1	–	Relative permittivity of the gate dielectric	0
54	**EPSROXO**	–	3.9	1	–	Geometry-independent parameter	1
55	**NEFF**	m^{-3}	$5 \cdot 10^{23}$	10^{20}	10^{26}	Effective substrate doping	0
56	**NSUBO**	m^{-3}	$4 \cdot 10^{23}$	10^{20}	–	Geometry independent part	1
57	**NSUBW**	–	0	–	–	Width dependence due to segregation	1
58	**WSEG**	m	10^{-8}	10^{-10}	–	Characteristic length for segregation	1
59	**NPCK**	m^{-3}	10^{24}	0	–	Pocket doping level	1
60	**NPCKW**	–	0	–	–	Width dependence of pocket doping **NPCK** due to segregation	1
61	**WSEGP**	m	10^{-8}	10^{-10}	–	Characteristic length for segregation of pocket doping	1
62	**LPCK**	m	10^{-8}	10^{-10}	–	Characteristic length for lateral doping profile	1
63	**LPCKW**	–	0	–	–	Width dependence of **LPCK** due to segregation	1
64	**FOL1**	–	0	–	–	First order length dependence of short channel body effect	1
65	**FOL2**	–	0	–	–	Second order length dependence of short channel body effect	1
66	**PONEFF**	m^{-3}	$5 \cdot 10^{23}$	–	–	Binning: geom. independent part	1
67	**PLNEFF**	m^{-3}	0	–	–	Binning: length dependence	1
68	**PWNEFF**	m^{-3}	0	–	–	Binning: width dependence	1
69	**PLWNEFF**	m^{-3}	0	–	–	Binning: area dependence	1
70	**GFACNUD**	–	1	0.01	–	Body-factor change due to NUD-effect	0

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
71	**GFACNUDO**	–	1	–	–	Geometry independent part	1
72	**GFACNUDL**	–	0	–	–	Length dependence	1
73	**GFACNUDLEXP**	–	1	–	–	Exponent for length dependence	1
74	**GFACNUDW**	–	0	–	–	Width dependence	1
75	**GFACNUDLW**	–	0	–	–	Area dependence	1
76	**POGFACNUD**	–	1	–	–	Binning: geom. independent part	1
77	**PLGFACNUD**	–	0	–	–	Binning: length dependence	1
78	**PWGFACNUD**	–	0	–	–	Binning: width dependence	1
79	**PLWGFACNUD**	–	0	–	–	Binning: area dependence	1
80	**VSBNUD**	V	0	0	–	Lower V_{SB}-value due to NUD-effect	0
81	**VSBNUDO**	V	0	0	–	Geometry-independent parameter	1
82	**POVSBNUD**	V	0	–	–	Binning: geom. independent part	1
83	**PLVSBNUD**	V	0	–	–	Binning: length dependence	1
84	**PWVSBNUD**	V	0	–	–	Binning: width dependence	1
85	**PLWVSBNUD**	V	0	–	–	Binning: area dependence	1
86	**DVSBNUD**	V	1	0.1	–	V_{SB}-range for NUD-effect	0
87	**DVSBNUDO**	V	1	0.1	–	Geometry-independent parameter	1
88	**DPHIB**	V	0	–	–	Offset voltage of φ_{B}	0
89	**DPHIBO**	V	0	–	–	Geometry independent part	1
90	**DPHIBL**	V	0	–	–	Length dependence	1
91	**DPHIBLEXP**	–	1	–	–	Exponent for length dependence	1
92	**DPHIBW**	V	0	–	–	Width dependence	1
93	**DPHIBLW**	V	0	–	–	Area dependence	1
94	**PODPHIB**	V	0	–	–	Binning: geom. independent part	1
95	**PLDPHIB**	V	0	–	–	Binning: length dependence	1
96	**PWDPHIB**	V	0	–	–	Binning: width dependence	1
97	**PLWDPHIB**	V	0	–	–	Binning: area dependence	1
98	**NP**	m^{-3}	10^{26}	0	–	Gate poly-silicon doping	0
99	**NPO**	m^{-3}	10^{26}	–	–	Geometry-independent part	1
100	**NPL**	–	0	–	–	Length dependence	1
101	**PONP**	m^{-3}	10^{26}	–	–	Binning: geom. independent part	1
102	**PLNP**	m^{-3}	0	–	–	Binning: length dependence	1
103	**PWNP**	m^{-3}	0	–	–	Binning: width dependence	1
104	**PLWNP**	m^{-3}	0	–	–	Binning: area dependence	1
105	**TOXOV**	m	$2 \cdot 10^{-9}$	10^{-10}	–	Overlap oxide thickness	0
106	**TOXOVO**	m	$2 \cdot 10^{-9}$	10^{-10}	–	Geometry-independent parameter	1

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
107	**TOXOVD**	m	$2 \cdot 10^{-9}$	10^{-10}	–	Overlap oxide thickness for drain side	0
108	**TOXOVDO**	m	$2 \cdot 10^{-9}$	10^{-10}	–	Geometry-independent parameter	1
109	**LOV**	m	10^{-8}	0	–	Overlap length for gate/drain and gate/source overlap capacitance	1
110	**LOVD**	m	10^{-8}	0	–	Overlap length for gate/drain overlap capacitance	1
111	**NOV**	m^{-3}	$5 \cdot 10^{25}$	10^{23}	10^{27}	Effective doping of overlap region	0
112	**NOVO**	m^{-3}	$5 \cdot 10^{25}$	10^{23}	10^{27}	Geometry-independent parameter	1
113	**PONOV**	m^{-3}	$5 \cdot 10^{25}$	–	–	Binning: geom. independent part	1
114	**PLNOV**	m^{-3}	0	–	–	Binning: length dependence	1
115	**PWNOV**	m^{-3}	0	–	–	Binning: width dependence	1
116	**PLWNOV**	m^{-3}	0	–	–	Binning: area dependence	1
117	**NOVD**	m^{-3}	$5 \cdot 10^{25}$	10^{23}	10^{27}	Effective doping of overlap region for drain side	0
118	**NOVDO**	m^{-3}	$5 \cdot 10^{25}$	10^{23}	10^{27}	Geometry-independent parameter	1
119	**PONOVD**	m^{-3}	$5 \cdot 10^{25}$	–	–	Binning: geom. independent part	1
120	**PLNOVD**	m^{-3}	0	–	–	Binning: length dependence	1
121	**PWNOVD**	m^{-3}	0	–	–	Binning: width dependence	1
122	**PLWNOVD**	m^{-3}	0	–	–	Binning: area dependence	1
				Interface States Parameters			
123	**CT**	–	0	0	–	Interface states factor	0
124	**CTO**	–	0	–	–	Geometry-independent part	1
125	**CTL**	–	0	–	–	Length dependence	1
126	**CTLEXP**	–	1	–	–	Exponent for length dependence	1
127	**CTW**	–	0	–	–	Width dependence	1
128	**CTLW**	–	0	–	–	Area dependence	1
129	**POCT**	–	0	–	–	Binning: geom. independent part	1
130	**PLCT**	–	0	–	–	Binning: length dependence	1
131	**PWCT**	–	0	–	–	Binning: width dependence	1
132	**PLWCT**	–	0	–	–	Binning: area dependence	1
133	**CTB**	–	0	0	0.5	Bulk voltage dependence of interface states factor	0
134	**CTBO**	–	0	0	0.5	Geometry-independent parameter	1
135	**POCTB**	–	0	–	–	Binning: geom. independent part	1
136	**PLCTB**	–	0	–	–	Binning: length dependence	1
137	**PWCTB**	–	0	–	–	Binning: width dependence	1
138	**PLWCTB**	–	0	–	–	Binning: area dependence	1

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
139	**CTG**	–	0	0	1	Gate voltage dependence of interface states factor	0
140	**CTGO**	–	0	0	1	Geometry-independent parameter	1
141	**POCTG**	–	0	–	–	Binning: geom. independent part	1
142	**PLCTG**	–	0	–	–	Binning: length dependence	1
143	**PWCTG**	–	0	–	–	Binning: width dependence	1
144	**PLWCTG**	–	0	–	–	Binning: area dependence	1
145	**STCT**	–	1	–	–	Temperature dependence of **CT**	0
146	**STCTO**	–	1	–	–	Geometry-independent parameter	1
147	**POSTCT**	–	1	–	–	Binning: geom. independent part	1
148	**PLSTCT**	–	0	–	–	Binning: length dependence	1
149	**PWSTCT**	–	0	–	–	Binning: width dependence	1
150	**PLWSTCT**	–	0	–	–	Binning: area dependence	1
						DIBL Parameters	
151	**CF**	–	0	0	–	DIBL parameter	0
152	**CFL**	–	0	–	–	Length dependence	1
153	**CFLEXP**	–	2	–	–	Exponent for length dependence	1
154	**CFW**	–	0	–	–	Width dependence	1
155	**POCF**	–	0	–	–	Binning: geom. independent part	1
156	**PLCF**	–	0	–	–	Binning: length dependence	1
157	**PWCF**	–	0	–	–	Binning: width dependence	1
158	**PLWCF**	–	0	–	–	Binning: area dependence	1
159	**CFB**	V^{-1}	0	0	1	Bulk voltage dependence of DIBL	0
160	**CFBO**	V^{-1}	0	0	1	Geometry-independent parameter	1
161	**POCFB**	V^{-1}	0	–	–	Binning: geom. independent part	1
162	**PLCFB**	V^{-1}	0	–	–	Binning: length dependence	1
163	**PWCFB**	V^{-1}	0	–	–	Binning: width dependence	1
164	**PLWCFB**	V^{-1}	0	–	–	Binning: area dependence	1
165	**CFD**	V^{-1}	0	0	–	Drain voltage dependence of DIBL	0
166	**CFDO**	V^{-1}	0	0	–	Geometry-independent parameter	1
167	**POCFD**	V^{-1}	0	–	–	Binning: geom. independent part	1
168	**PLCFD**	V^{-1}	0	–	–	Binning: length dependence	1
169	**PWCFD**	V^{-1}	0	–	–	Binning: width dependence	1
170	**PLWCFD**	V^{-1}	0	–	–	Binning: area dependence	1
						Subthreshold Slope Parameters	
171	**PSCE**	–	0	0	–	Subthreshold slope coefficient for short channel transistor	0

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
172	**PSCEL**	–	0	–	–	Length dependence	1
173	**PSCELEXP**	–	2	–	–	Exponent for length dependence	1
174	**PSCEW**	–	0	–	–	Width dependence	1
175	**POPSCE**	–	0	–	–	Binning: geom. independent part	1
176	**PLPSCE**	–	0	–	–	Binning: length dependence	1
177	**PWPSCE**	–	0	–	–	Binning: width dependence	1
178	**PLWPSCE**	–	0	–	–	Binning: area dependence	1
179	**PSCEB**	V^{-1}	0	0	1	Bulk voltage dependence parameter of subthreshold slope coefficient for short channel transistor	0
180	**PSCEBO**	V^{-1}	0	0	1	Geometry-independent parameter	1
181	**POPSCEB**	V^{-1}	0	–	–	Binning: geom. independent part	1
182	**PLPSCEB**	V^{-1}	0	–	–	Binning: length dependence	1
183	**PWPSCEB**	V^{-1}	0	–	–	Binning: width dependence	1
184	**PLWPSCEB**	V^{-1}	0	–	–	Binning: area dependence	1
185	**PSCED**	V^{-1}	0	0	–	Drain voltage dependence parameter of subthreshold slope coefficient for short channel transistor	0
186	**PSCEDO**	V^{-1}	0	0	–	Geometry-independent parameter	1
187	**POPSCED**	V^{-1}	0	–	–	Binning: geom. independent part	1
188	**PLPSCED**	V^{-1}	0	–	–	Binning: length dependence	1
189	**PWPSCED**	V^{-1}	0	–	–	Binning: width dependence	1
190	**PLWPSCED**	V^{-1}	0	–	–	Binning: area dependence	1
				Mobility Parameters			
191	**BETN**	$\mathrm{m}^2/\mathrm{V/s}$	$3 \cdot 10^{-2}$	0	–	Product of channel aspect ratio and zero-field mobility at **TR**	0
192	**UO**	$\mathrm{m}^2/\mathrm{V/s}$	$3 \cdot 10^{-2}$	0	–	Zero-field mobility at **TR**	1
193	**FBET1**	–	0	–	–	Relative mobility decrease due to first lateral profile	1
194	**FBET1W**	–	0	–	–	Width dependence of relative mobility decrease due to first lateral profile	1
195	**LP1**	m	10^{-8}	10^{-10}	–	Mobility-related characteristic length of first lateral profile	1
196	**LP1W**	–	0	–	–	Width dependence of mobility-related characteristic length of first lateral profile	1
197	**FBET2**	–	0	–	–	Relative mobility decrease due to second lateral profile	1

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
198	**LP2**	m	10^{-8}	10^{-10}	–	Mobility-related characteristic length of second lateral profile	1
199	**BETW1**	–	0	–	–	First higher-order width scaling coefficient of **BETN**	1
200	**BETW2**	–	0	–	–	Second higher-order width scaling coefficient of **BETN**	1
201	**WBET**	m	10^{-9}	10^{-10}	–	Characteristic width for width scaling of **BETN**	1
202	**POBETN**	$m^2/V/s$	$3 \cdot 10^{-2}$	–	–	Binning: geom. independent part	1
203	**PLBETN**	$m^2/V/s$	0	–	–	Binning: length dependence	1
204	**PWBETN**	$m^2/V/s$	0	–	–	Binning: width dependence	1
205	**PLWBETN**	$m^2/V/s$	0	–	–	Binning: area dependence	1
206	**STBET**	–	1	–	–	Temperature dependence of **BETN**	0
207	**STBETO**	–	1	–	–	Binning: geom. independent part	1
208	**STBETL**	–	0	–	–	Length dependence	1
209	**STBETW**	–	0	–	–	Width dependence	1
210	**STBETLW**	–	0	–	–	Area dependence	1
211	**POSTBET**	–	1	–	–	Binning: geom. independent part	1
212	**PLSTBET**	–	0	–	–	Binning: length dependence	1
213	**PWSTBET**	–	0	–	–	Binning: width dependence	1
214	**PLWSTBET**	–	0	–	–	Binning: area dependence	1
215	**MUE**	m/V	0.5	0	–	High field mobility reduction coefficient at **TR**	0
216	**MUEO**	m/V	0.5	–	–	Geometry independent part	1
217	**MUEW**	–	0	–	–	Width dependence	1
218	**POMUE**	m/V	0.5	–	–	Binning: geom. independent part	1
219	**PLMUE**	m/V	0	–	–	Binning: length dependence	1
220	**PWMUE**	m/V	0	–	–	Binning: width dependence	1
221	**PLWMUE**	m/V	0	–	–	Binning: area dependence	1
222	**STMUE**	–	0	–	–	Temperature dependence of **MUE**	0
223	**STMUEO**	–	0	–	–	Geometry-independent parameter	1
224	**THEMU**	–	1.5	0	–	High field mobility reduction exponent at **TR**	0
225	**THEMUO**	–	1.5	0	–	Geometry-independent parameter	1
226	**POTHEMU**	–	1.5	–	–	Binning: geom. independent part	1
227	**PLTHEMU**	–	0	–	–	Binning: length dependence	1
228	**PWTHEMU**	–	0	–	–	Binning: width dependence	1
229	**PLWTHEMU**	–	0	–	–	Binning: area dependence	1
230	**STTHEMU**	–	1.5	–	–	Temperature dependence of **THEMU**	0

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
231	**STTHEMUO**	–	1.5	–	–	Geometry-independent parameter	1
232	**CS**	–	0	0	–	Coulomb scattering parameter at **TR**	0
233	**CSO**	–	0	–	–	Geometry independent part	1
234	**CSL**	–	0	–	–	Length dependence	1
235	**CSLEXP**	–	1	–	–	Exponent for length dependence	1
236	**CSW**	–	0	–	–	Width dependence	1
237	**CSLW**	–	0	–	–	Area dependence	1
238	**POCS**	–	0	–	–	Binning: geom. independent part	1
239	**PLCS**	–	0	–	–	Binning: length dependence	1
240	**PWCS**	–	0	–	–	Binning: width dependence	1
241	**PLWCS**	–	0	–	–	Binning: area dependence	1
242	**STCS**	–	0	–	–	Temperature dependence of **CS**	0
243	**STCSO**	–	0	–	–	Geometry-independent parameter	1
244	**THECS**	–	2	0	–	Coulomb scattering exponent at **TR**	0
245	**THECSO**	–	2	0	–	Geometry-independent parameter	1
246	**POTHECS**	–	2	–	–	Binning: geom. independent part	1
247	**PLTHECS**	–	0	–	–	Binning: length dependence	1
248	**PWTHECS**	–	0	–	–	Binning: width dependence	1
249	**PLWTHECS**	–	0	–	–	Binning: area dependence	1
250	**STTHECS**	–	0	–	–	Temperature dependence of **THECS**	0
251	**STTHECSO**	–	0	–	–	Geometry-independent parameter	1
252	**XCOR**	V^{-1}	0	0	–	Non-universality parameter	0
253	**XCORO**	V^{-1}	0	–	–	Geometry independent part	1
254	**XCORL**	–	0	–	–	Length dependence	1
255	**XCORW**	–	0	–	–	Width dependence	1
256	**XCORLW**	–	0	–	–	Area dependence	1
257	**POXCOR**	V^{-1}	0	–	–	Binning: geom. independent part	1
258	**PLXCOR**	V^{-1}	0	–	–	Binning: length dependence	1
259	**PWXCOR**	V^{-1}	0	–	–	Binning: width dependence	1
260	**PLWXCOR**	V^{-1}	0	–	–	Binning: area dependence	1
261	**STXCOR**	–	0	–	–	Temperature dependence of **XCOR**	0
262	**STXCORO**	–	0	–	–	Geometry-independent parameter	1
263	**FETA**	–	1	0	–	Effective field parameter	0
264	**FETAO**	–	1	0	–	Geometry-independent parameter	1

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
			Series Resistance Parameters				
265	**RS**	Ω	50	0	–	Source/drain series resistance at **TR**	0
266	**RSW1**	Ω	50	–	–	First order of width dependence	1
267	**RSW2**	–	0	–	–	Second order of width dependence	1
268	**PORS**	Ω	50	–	–	Binning: geom. independent part	1
269	**PLRS**	Ω	0	–	–	Binning: length dependence	1
270	**PWRS**	Ω	0	–	–	Binning: width dependence	1
271	**PLWRS**	Ω	0	–	–	Binning: area dependence	1
272	**STRS**	–	1	–	–	Temperature dependence of **RS**	0
273	**STRSO**	–	1	–	–	Geometry-independent parameter	1
274	**POSTRS**	–	1	–	–	Binning: geom. independent part	1
275	**PLSTRS**	–	0	–	–	Binning: length dependence	1
276	**PWSTRS**	–	0	–	–	Binning: width dependence	1
277	**PLWSTRS**	–	0	–	–	Binning: area dependence	1
278	**RSB**	V^{-1}	0	−0.5	1	Bulk voltage dependence of series resistance	0
279	**RSBO**	V^{-1}	0	−0.5	1	Geometry-independent parameter	1
280	**PORSB**	V^{-1}	0	–	–	Binning: geom. independent part	1
281	**PLRSB**	V^{-1}	0	–	–	Binning: length dependence	1
282	**PWRSB**	V^{-1}	0	–	–	Binning: width dependence	1
283	**PLWRSB**	V^{-1}	0	–	–	Binning: area dependence	1
284	**RSG**	V^{-1}	0	−0.5	–	Gate voltage dependence of series resistance	0
285	**RSGO**	V^{-1}	0	−0.5	–	Geometry-independent parameter	1
286	**PORSG**	V^{-1}	0	–	–	Binning: geom. independent part	1
287	**PLRSG**	V^{-1}	0	–	–	Binning: length dependence	1
288	**PWRSG**	V^{-1}	0	–	–	Binning: width dependence	1
289	**PLWRSG**	V^{-1}	0	–	–	Binning: area dependence	1
			Velocity Saturation Parameters				
290	**THESAT**	V^{-1}	0.3	0	–	Velocity saturation parameter at **TR**	0
291	**THESATO**	V^{-1}	0	–	–	Geometry independent part	1
292	**THESATL**	V^{-1}	0.3	–	–	Length dependence	1
293	**THESATLEXP**	–	1	–	–	Exponent for length dependence	1
294	**THESATW**	–	0	–	–	Width dependence	1
295	**THESATLW**	–	0	–	–	Area dependence	1
296	**POTHESAT**	V^{-1}	0.3	–	–	Binning: geom. independent part	1

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
297	**PLTHESAT**	V^{-1}	0	–	–	Binning: length dependence	1
298	**PWTHESAT**	V^{-1}	0	–	–	Binning: width dependence	1
299	**PLWTHESAT**	V^{-1}	0	–	–	Binning: area dependence	1
300	**STTHESAT**	–	1	–	–	Temperature dependence of **THESAT**	0
301	**STTHESATO**	–	1	–	–	Geometry independent temperature dependence	1
302	**STTHESATL**	–	0	–	–	Length dependence	1
303	**STTHESATW**	–	0	–	–	Width dependence	1
304	**STTHESATLW**	–	0	–	–	Area dependence	1
305	**POSTTHESAT**	–	1	–	–	Binning: geom. independent part	1
306	**PLSTTHESAT**	–	0	–	–	Binning: length dependence	1
307	**PWSTTHESAT**	–	0	–	–	Binning: width dependence	1
308	**PLWSTTHESAT**	–	0	–	–	Binning: area dependence	1
309	**THESATB**	V^{-1}	0	−0.5	1	Bulk voltage dependence of velocity saturation	0
310	**THESATBO**	V^{-1}	0	−0.5	1	Geometry-independent parameter	1
311	**POTHESATB**	V^{-1}	0	–	–	Binning: geom. independent part	1
312	**PLTHESATB**	V^{-1}	0	–	–	Binning: length dependence	1
313	**PWTHESATB**	V^{-1}	0	–	–	Binning: width dependence	1
314	**PLWTHESATB**	V^{-1}	0	–	–	Binning: area dependence	1
315	**THESATG**	V^{-1}	0	−0.5	–	Gate voltage dependence of velocity saturation	0
316	**THESATGO**	V^{-1}	0	−0.5	–	Geometry-independent parameter	1
317	**POTHESATG**	V^{-1}	0	–	–	Binning: geom. independent part	1
318	**PLTHESATG**	V^{-1}	0	–	–	Binning: length dependence	1
319	**PWTHESATG**	V^{-1}	0	–	–	Binning: width dependence	1
320	**PLWTHESATG**	V^{-1}	0	–	–	Binning: area dependence	1
321	**THESATT**	–	1	0.01	–	Threshold parameter of gate voltage dependence of velocity saturation	0
322	**THESATTO**	–	1	0.01	–	Geometry-independent parameter	1
				Linear to saturation transition parameters			
323	**AX**	-	8	2	–	Linear/saturation transition factor	0
324	**AXO**	–	16	–	–	Geometry independent	1
325	**AXL**	–	1	0	–	Length dependence	1
326	**POAX**	-	8	–	–	Binning: geom. independent part	1
327	**PLAX**	-	0	–	–	Binning: length dependence	1
328	**PWAX**	-	0	–	–	Binning: width dependence	1

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
329	**PLWAX**	-	0	–	–	Binning: area dependence	1
	Channel Length Modulation (CLM) Parameters						
330	**ALP**	–	0.01	0	–	CLM pre-factor	0
331	**ALPL**	–	0.01	–	–	Length dependence	1
332	**ALPLEXP**	–	1	–	–	Exponent for length dependence	1
333	**ALPW**	–	0	–	–	Width dependence	1
334	**POALP**	–	0.01	–	–	Binning: geom. independent part	1
335	**PLALP**	–	0	–	–	Binning: length dependence	1
336	**PWALP**	–	0	–	–	Binning: width dependence	1
337	**PLWALP**	–	0	–	–	Binning: area dependence	1
338	**ALP1**	V	0	0	–	CLM enhancement factor above threshold	0
339	**ALP1L1**	V	0	–	–	Length dependence	1
340	**ALP1LEXP**	–	0.5	–	–	Exponent for length dependence	1
341	**ALP1L2**	–	0	0	–	Second order length dependence	1
342	**ALP1W**	–	0	–	–	Width dependence	1
343	**POALP1**	V	0	–	–	Binning: geom. independent part	1
344	**PLALP1**	V	0	–	–	Binning: length dependence	1
345	**PWALP1**	V	0	–	–	Binning: width dependence	1
346	**PLWALP1**	V	0	–	–	Binning: area dependence	1
347	**ALP2**	V^{-1}	0	0	–	CLM enhancement factor below threshold	0
348	**ALP2L1**	V	0	–	–	Length dependence	1
349	**ALP2LEXP**	–	0.5	–	–	Exponent for length dependence	1
350	**ALP2L2**	–	0	0	–	Second order length dependence	1
351	**ALP2W**	–	0	–	–	Width dependence	1
352	**POALP2**	V^{-1}	0	–	–	Binning: geom. independent part	1
353	**PLALP2**	V^{-1}	0	–	–	Binning: length dependence	1
354	**PWALP2**	V^{-1}	0	–	–	Binning: width dependence	1
355	**PLWALP2**	V^{-1}	0	–	–	Binning: area dependence	1
356	**VP**	V	0.05	10^{-10}	–	CLM logarithmic dependence factor	0
357	**VPO**	V	0.05	10^{-10}	–	Geometry-independent parameter	1
	Impact Ionization (II) Parameters						
358	**A1**	–	1	0	–	Impact-ionization pre-factor	0
359	**A1O**	–	1	–	–	Geometry independent part	1
360	**A1L**	–	0	–	–	Length dependence	1
361	**A1W**	–	0	–	–	Width dependence	1

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
362	**POA1**	–	1	–	–	Binning: geom. independent part	1
363	**PLA1**	–	0	–	–	Binning: length dependence	1
364	**PWA1**	–	0	–	–	Binning: width dependence	1
365	**PLWA1**	–	0	–	–	Binning: area dependence	1
366	**A2**	V	10	0	–	Impact-ionization exponent at **TR**	0
367	**A2O**	V	10	0	–	Geometry-independent parameter	1
368	**STA2**	V	0	–	–	Temperature dependence of **A2**	0
369	**STA2O**	V	0	–	–	Geometry independent part	1
370	**POSTA2**	V	0	–	–	Binning: geom. independent part	1
371	**PLSTA2**	V	0	–	–	Binning: length dependence	1
372	**PWSTA2**	V	0	–	–	Binning: width dependence	1
373	**PLWSTA2**	V	0	–	–	Binning: area dependence	1
374	**A3**	–	1	0	–	Saturation-voltage dependence of impact-ionization	0
375	**A3O**	–	1	–	–	Geometry independent part	1
376	**A3L**	–	0	–	–	Length dependence	1
377	**A3W**	–	0	–	–	Width dependence	1
378	**POA3**	–	1	–	–	Binning: geom. independent part	1
379	**PLA3**	–	0	–	–	Binning: length dependence	1
380	**PWA3**	–	0	–	–	Binning: width dependence	1
381	**PLWA3**	–	0	–	–	Binning: area dependence	1
382	**A4**	$V^{-\frac{1}{2}}$	0	0	–	Bulk voltage dependence of impact-ionization	0
383	**A4O**	$V^{-\frac{1}{2}}$	0	–	–	Geometry independent part	1
384	**A4L**	–	0	–	–	Length dependence	1
385	**A4W**	–	0	–	–	Width dependence	1
386	**POA4**	$V^{-\frac{1}{2}}$	0	–	–	Binning: geom. independent part	1
387	**PLA4**	$V^{-\frac{1}{2}}$	0	–	–	Binning: length dependence	1
388	**PWA4**	$V^{-\frac{1}{2}}$	0	–	–	Binning: width dependence	1
389	**PLWA4**	$V^{-\frac{1}{2}}$	0	–	–	Binning: area dependence	1
Gate Current Parameters							
390	**GCO**	–	0	−10	10	Gate tunnelling energy adjustment	0
391	**GCOO**	–	0	−10	10	Geometry-independent parameter	1
392	**IGINV**	A	0	0	–	Gate channel current pre-factor	0
393	**IGINVLW**	A	0	0	–	Area dependence parameter	1
394	**POIGINV**	A	0	–	–	Binning: geom. independent part	1
395	**PLIGINV**	A	0	–	–	Binning: length dependence	1

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
396	**PWIGINV**	A	0	–	–	Binning: width dependence	1
397	**PLWIGINV**	A	0	–	–	Binning: area dependence	1
398	**IGOV**	A	0	0	–	Gate overlap current pre-factor	0
399	**IGOVW**	A	0	0	–	Width dependence parameter	1
400	**POIGOV**	A	0	–	–	Binning: geom. independent part	1
401	**PLIGOV**	A	0	–	–	Binning: length dependence	1
402	**PWIGOV**	A	0	–	–	Binning: width dependence	1
403	**PLWIGOV**	A	0	–	–	Binning: area dependence	1
404	**IGOVD**	A	0	0	–	Gate overlap current pre-factor for drain side	0
405	**IGOVDW**	A	0	0	–	Width dependence parameter	1
406	**POIGOVD**	A	0	–	–	Binning: geom. independent part	1
407	**PLIGOVD**	A	0	–	–	Binning: length dependence	1
408	**PWIGOVD**	A	0	–	–	Binning: width dependence	1
409	**PLWIGOVD**	A	0	–	–	Binning: area dependence	1
410	**STIG**	–	2	–	–	Temperature dependence of **IGINV** and **IGOV**	0
411	**STIGO**	–	2	–	–	Geometry-independent parameter	1
412	**POSTIG**	–	2	–	–	Binning: geom. independent part	1
413	**PLSTIG**	–	0	–	–	Binning: length dependence	1
414	**PWSTIG**	–	0	–	–	Binning: width dependence	1
415	**PLWSTIG**	–	0	–	–	Binning: area dependence	1
416	**GC2**	–	0.375	0	10	Gate current slope factor	0
417	**GC2O**	–	0.375	0	10	Geometry-independent parameter	1
418	**GC3**	–	0.063	−2	2	Gate current curvature factor	0
419	**GC3O**	–	0.063	−2	2	Geometry-independent parameter	1
420	**GC2OV**	–	**GC2**	0	10	Gate overlap current slope factor	0
421	**GC2OVO**	–	**GC2O**	0	10	Geometry-independent parameter	1
422	**GC3OV**	–	**GC3**	−2	2	Gate overlap current curvature factor	0
423	**GC3OVO**	–	**GC3O**	−2	2	Geometry-independent parameter	1
424	**CHIB**	V	3.1	1	–	Tunnelling barrier height	0
425	**CHIBO**	V	3.1	1	–	Geometry-independent parameter	1
						Gate-Induced Drain Leakage (GIDL) Parameters	
426	**AGIDL**	A/V^3	0	0	–	GIDL pre-factor	0
427	**AGIDLW**	A/V^3	0	0	–	Width dependence parameter	1

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
428	**POAGIDL**	A/V^3	0	–	–	Binning: geom. independent part	1
429	**PLAGIDL**	A/V^3	0	–	–	Binning: length dependence	1
430	**PWAGIDL**	A/V^3	0	–	–	Binning: width dependence	1
431	**PLWAGIDL**	A/V^3	0	–	–	Binning: area dependence	1
432	**AGIDLD**	A/V^3	0	0	–	GIDL pre-factor for drain side	0
433	**AGIDLDW**	A/V^3	0	0	–	Width dependence parameter	1
434	**POAGIDLD**	A/V^3	0	–	–	Binning: geom. independent part	1
435	**PLAGIDLD**	A/V^3	0	–	–	Binning: length dependence	1
436	**PWAGIDLD**	A/V^3	0	–	–	Binning: width dependence	1
437	**PLWAGIDLD**	A/V^3	0	–	–	Binning: area dependence	1
438	**BGIDL**	V	41	0	–	GIDL probability factor at **TR**	0
439	**BGIDLO**	V	41	0	–	Geometry-independent parameter	1
440	**BGIDLD**	V	41	0	–	GIDL probability factor at **TR** for drain side	0
441	**BGIDLDO**	V	41	0	–	Geometry-independent parameter	1
442	**STBGIDL**	V/K	0	–	–	Temperature dependence of **BGIDL**	0
443	**STBGIDLO**	V/K	0	–	–	Geometry-independent parameter	1
444	**POSTBGIDL**	V/K	0	–	–	Binning: geom. independent part	1
445	**PLSTBGIDL**	V/K	0	–	–	Binning: length dependence	1
446	**PWSTBGIDL**	V/K	0	–	–	Binning: width dependence	1
447	**PLWSTBGIDL**	V/K	0	–	–	Binning: area dependence	1
448	**STBGIDLD**	V/K	0	–	–	Temperature dependence of **BGIDLD**	0
449	**STBGIDLDO**	V/K	0	–	–	Geometry-independent parameter	1
450	**POSTBGIDLD**	V/K	0	–	–	Binning: geom. independent part	1
451	**PLSTBGIDLD**	V/K	0	–	–	Binning: length dependence	1
452	**PWSTBGIDLD**	V/K	0	–	–	Binning: width dependence	1
453	**PLWSTBGIDLD**	V/K	0	–	–	Binning: area dependence	1
454	**CGIDL**	–	0	–	–	Bulk voltage dependence of GIDL	0
455	**CGIDLO**	–	0	–	–	Geometry-independent parameter	1
456	**CGIDLD**	–	0	–	–	Bulk voltage dependence of GIDL for drain side	0
457	**CGIDLDO**	–	0	–	–	Geometry-independent parameter	1
			Charge Model Parameters				
458	**COX**	F	10^{-14}	0	–	Oxide capacitance for the intrinsic channel	0

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
459	**POCOX**	F	10^{-14}	–	–	Binning: geom. independent part	1
460	**PLCOX**	F	0	–	–	Binning: length dependence	1
461	**PWCOX**	F	0	–	–	Binning: width dependence	1
462	**PLWCOX**	F	0	–	–	Binning: area dependence	1
463	**DELVTAC**	V	0	–	–	φ_B offset in separate charge calculation (**SWDELVTAC** $= 1$)	0
464	**DELVTACO**	V	0	–	–	Geometry independent part	1
465	**DELVTACL**	V	0	–	–	Length dependence	1
466	**DELVTACLEXP**	–	1	–	–	Exponent for length dependence	1
467	**DELVTACW**	V	0	–	–	Width dependence	1
468	**DELVTACLW**	V	0	–	–	Area dependence	1
469	**PODELVTAC**	V	0	–	–	Binning: geom. independent part	1
470	**PLDELVTAC**	V	0	–	–	Binning: length dependence	1
471	**PWDELVTAC**	V	0	–	–	Binning: width dependence	1
472	**PLWDELVTAC**	V	0	–	–	Binning: area dependence	1
473	**FACNEFFAC**	–	1	0	–	Pre-factor for effective substrate doping in separate charge calculation (**SWDELVTAC** $= 1$)	0
474	**FACNEFFACO**	–	1	–	–	Geometry independent part	1
475	**FACNEFFACL**	–	0	–	–	Length dependence	1
476	**FACNEFFACW**	–	0	–	–	Width dependence	1
477	**FACNEFFACLW**	–	0	–	–	Area dependence	1
478	**POFACNEFFAC**	–	1	–	–	Binning: geom. independent part	1
479	**PLFACNEFFAC**	–	0	–	–	Binning: length dependence	1
480	**PWFACNEFFAC**	–	0	–	–	Binning: width dependence	1
481	**PLWFACNEFFAC**	–	0	–	–	Binning: area dependence	1
482	**THESATAC**	V^{-1}	**THESAT**	0	–	Velocity saturation parameter at **TR** of the charge model when **SWQSAT**=1	0
483	**THESATACO**	V^{-1}	**THESATO**	–	–	Geometry independent part	1
484	**THESATACL**	V^{-1}	**THESATL**	–	–	Length dependence	1
485	**THESATACLEXP**	–	**THESATLEXP**	–	–	Exponent for length dependence	1
486	**THESATACW**	–	**THESATW**	–	–	Width dependence	1
487	**THESATACLW**	–	**THESATLW**	–	–	Area dependence	1
488	**POTHESATAC**	V^{-1}	**POTHESAT**	–	–	Binning: geom. independent part	1
489	**PLTHESATAC**	V^{-1}	**PLTHESAT**	–	–	Binning: length dependence	1
490	**PWTHESATAC**	V^{-1}	**PWTHESAT**	–	–	Binning: width dependence	1
491	**PLWTHESATAC**	V^{-1}	**PLWTHESAT**	–	–	Binning: area dependence	1
492	**AXAC**	-	**AX**	2	–	Linear/saturation transition factor of the charge model when **SWQSAT**=1	0

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
493	**AXACO**	–	**AXO**	–	–	Geometry independent	1
494	**AXACL**	–	**AXL**	0	–	Length dependence	1
495	**POAXAC**	–	**POAX**	–	–	Binning: geom. independent part	1
496	**PLAXAC**	–	**PLAX**	–	–	Binning: length dependence	1
497	**PWAXAC**	–	**PWAX**	–	–	Binning: width dependence	1
498	**PLWAXAC**	–	**PLWAX**	–	–	Binning: area dependence	1
499	**ALPAC**	–	0	–	–	CLM pre-factor of the charge model	0
500	**ALPACL**	–	0	–	–	Length dependence	1
501	**ALPACLEXP**	–	1	–	–	Exponent for length dependence	1
502	**ALPACW**	–	0	–	–	Width dependence	1
503	**POALPAC**	–	0	–	–	Binning: geom. independent part	1
504	**PLALPAC**	–	0	–	–	Binning: length dependence	1
505	**PWALPAC**	–	0	–	–	Binning: width dependence	1
506	**PLWALPAC**	–	0	–	–	Binning: area dependence	1
507	**ALP1AC**	V	0	0	–	CLM enhancement factor above threshold of the charge model	0
508	**ALP1ACL1**	V	0	–	–	Length dependence	1
509	**ALP1ACLEXP**	–	0.5	–	–	Exponent for length dependence	1
510	**ALP1ACL2**	–	0	0	–	Second order length dependence	1
511	**ALP1ACW**	–	0	–	–	Width dependence	1
512	**POALP1AC**	V	0	–	–	Binning: geom. independent part	1
513	**PLALP1AC**	V	0	–	–	Binning: length dependence	1
514	**PWALP1AC**	V	0	–	–	Binning: width dependence	1
515	**PLWALP1AC**	V	0	–	–	Binning: area dependence	1
516	**CGOV**	F	10^{-15}	0	–	Oxide capacitance for gate–drain/source overlap	0
517	**POCGOV**	F	10^{-15}	–	–	Binning: geom. independent part	1
518	**PLCGOV**	F	0	–	–	Binning: length dependence	1
519	**PWCGOV**	F	0	–	–	Binning: width dependence	1
520	**PLWCGOV**	F	0	–	–	Binning: area dependence	1
521	**CGOVD**	F	10^{-15}	0	–	Oxide capacitance for gate–drain overlap	0
522	**POCGOVD**	F	10^{-15}	–	–	Binning: geom. independent part	1
523	**PLCGOVD**	F	0	–	–	Binning: length dependence	1
524	**PWCGOVD**	F	0	–	–	Binning: width dependence	1
525	**PLWCGOVD**	F	0	–	–	Binning: area dependence	1
526	**FCGOVACC**		0.5	0	1	Factor for overlap capacitances in accumulation regime	0

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
527	**FCGOVACCO**		0.5	0	1	Geometry-independent parameter	1
528	**FCGOVACCD**		0.5	0	1	Factor for overlap capacitances in accumulation regime for drain side	0
529	**FCGOVACCDO**		0.5	0	1	Geometry-independent parameter	1
530	**CGOVACCG**		1	0.1	1	Gate voltage dependence parameter of overlap capacitances in accumulation regime	0
531	**CGOVACCGO**		1	0.1	1	Geometry-independent parameter	1
532	**CGBOV**	F	10^{-15}	0	–	Oxide capacitance for gate–bulk overlap	0
533	**CGBOVL**	F	10^{-15}	0	–	Length dependence parameter	1
534	**POCGBOV**	F	10^{-15}	–	–	Binning: geom. independent part	1
535	**PLCGBOV**	F	0	–	–	Binning: length dependence	1
536	**PWCGBOV**	F	0	–	–	Binning: width dependence	1
537	**PLWCGBOV**	F	0	–	–	Binning: area dependence	1
538	**CINR**	F	$5 \cdot 10^{-16}$	0	–	Inner fringe capacitance	0
539	**CINRW**	F	$5 \cdot 10^{-16}$	0	–	Width dependence parameter	1
540	**POCINR**	F	$5 \cdot 10^{-16}$	–	–	Binning: geom. independent part	1
541	**PLCINR**	F	0	–	–	Binning: length dependence	1
542	**PWCINR**	F	0	–	–	Binning: width dependence	1
543	**PLWCINR**	F	0	–	–	Binning: area dependence	1
544	**CINRD**	F	$5 \cdot 10^{-16}$	0	–	Inner fringe capacitance for drain side	0
545	**CINRWD**	F	$5 \cdot 10^{-16}$	0	–	Width dependence parameter	1
546	**POCINRD**	F	$5 \cdot 10^{-16}$	–	–	Binning: geom. independent part	1
547	**PLCINRD**	F	0	–	–	Binning: length dependence	1
548	**PWCINRD**	F	0	–	–	Binning: width dependence	1
549	**PLWCINRD**	F	0	–	–	Binning: area dependence	1
550	**DVFBINR**	V	0	–	–	Flat-band voltage offset of inner fringe capacitances	0
551	**DVFBINRO**	V	0	–	–	Geometry-independent parameter	1
552	**FCINRDEP**	–	0.3	0	1	Bias dependence parameter of inner fringe capacitances in depletion regime	0
553	**FCINRDEPO**	–	0.3	0	1	Geometry-independent parameter	1
554	**FCINRACC**	–	0.5	0	–	Bias dependence parameter of inner fringe capacitances in accumulation regime	0

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
555	**FCINRACCO**	–	0.5	0	–	Geometry-independent parameter	1
556	**AXINR**	–	0.4	0.1	4	Accumulation/depletion transition factor of inner fringe capacitances	0
557	**AXINRO**	–	0.4	0.1	4	Geometry-independent parameter	1
558	**CFR**	F	10^{-15}	0	–	Outer fringe capacitance	0
559	**CFRW**	F	10^{-15}	0	–	Width dependence parameter	1
560	**POCFR**	F	10^{-15}	–	–	Binning: geom. independent part	1
561	**PLCFR**	F	0	–	–	Binning: length dependence	1
562	**PWCFR**	F	0	–	–	Binning: width dependence	1
563	**PLWCFR**	F	0	–	–	Binning: area dependence	1
564	**CFRD**	F	10^{-15}	0	–	Outer fringe capacitance for drain side	0
565	**CFRDW**	F	10^{-15}	0	–	Width dependence parameter	1
566	**POCFRD**	F	10^{-15}	–	–	Binning: geom. independent part	1
567	**PLCFRD**	F	0	–	–	Binning: length dependence	1
568	**PWCFRD**	F	0	–	–	Binning: width dependence	1
569	**PLWCFRD**	F	0	–	–	Binning: area dependence	1
			Noise Model Parameters				
570	**FNT**	–	1	0	–	Thermal noise coefficient	0
571	**FNTO**	–	1	0	–	Geometry-independent parameter	1
572	**FNTEXC**	–	0	0	–	Excess noise coefficient	0
573	**FNTEXCL**	–	0	0	–	Length dependence parameter	1
574	**POFNTEXC**	–	0	–	–	Binning: geom. independent part	1
575	**PLFNTEXC**	–	0	–	–	Binning: length dependence	1
576	**PWFNTEXC**	–	0	–	–	Binning: width dependence	1
577	**PLWFNTEXC**	–	0	–	–	Binning: area dependence	1
578	**NFA**	V^{-1}/m^4	$8 \cdot 10^{22}$	0	–	First coefficient of flicker noise	0
579	**NFALW**	V^{-1}/m^4	$8 \cdot 10^{22}$	0	–	Width dependence parameter	1
580	**PONFA**	V^{-1}/m^4	$8 \cdot 10^{22}$	–	–	Binning: geom. independent part	1
581	**PLNFA**	V^{-1}/m^4	0	–	–	Binning: length dependence	1
582	**PWNFA**	V^{-1}/m^4	0	–	–	Binning: width dependence	1
583	**PLWNFA**	V^{-1}/m^4	0	–	–	Binning: area dependence	1
584	**NFB**	V^{-1}/m^2	$3 \cdot 10^{7}$	0	–	Second coefficient of flicker noise	0
585	**NFBLW**	V^{-1}/m^2	$3 \cdot 10^{7}$	0	–	Width dependence parameter	1
586	**PONFB**	V^{-1}/m^2	$3 \cdot 10^{7}$	–	–	Binning: geom. independent part	1
587	**PLNFB**	V^{-1}/m^2	0	–	–	Binning: length dependence	1

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
588	**PWNFB**	V^{-1}/m^2	0	–	–	Binning: width dependence	1
589	**PLWNFB**	V^{-1}/m^2	0	–	–	Binning: area dependence	1
590	**NFC**	V^{-1}	0	0	–	Third coefficient of flicker noise	0
591	**NFCLW**	V^{-1}	0	0	–	Width dependence parameter	1
592	**PONFC**	V^{-1}	0	–	–	Binning: geom. independent part	1
593	**PLNFC**	V^{-1}	0	–	–	Binning: length dependence	1
594	**PWNFC**	V^{-1}	0	–	–	Binning: width dependence	1
595	**PLWNFC**	V^{-1}	0	–	–	Binning: area dependence	1
596	**EF**	–	1	0	–	Flicker noise frequency exponent	0
597	**EFO**	–	1	0	–	Geometry-independent parameter	1
598	**LINTNOI**	m	0	–	–	Length offset for flicker noise	1
599	**ALPNOI**	–	2	–	–	Exponent for length offset	1
						Edge Transistors Model Parameters	
600	**WEDGE**	m	10^{-8}	0	–	Electrical width of edge transistor per side	1
601	**WEDGEW**	m	0	0	–	Main transistor width dependence of **WEDGE**	1
602	**VFBEDGE**	V	-1	–	–	Flat-band voltage of edge transistors at **TR**	0
603	**VFBEDGEO**	V	-1	–	–	Geometry-independent parameter	1
604	**POVFBEDGE**	V	-1	–	–	Binning: geom. independent part	1
605	**PLVFBEDGE**	V	0	–	–	Binning: length dependence	1
606	**PWVFBEDGE**	V	0	–	–	Binning: width dependence	1
607	**PLWVFBEDGE**	V	0	–	–	Binning: area dependence	1
608	**STVFBEDGE**	V/K	$5 \cdot 10^{-4}$	–	–	Temperature dependence of **VFBEDGE**	0
609	**STVFBEDGEO**	V/K	$5 \cdot 10^{-4}$	–	–	Geometry independent part	1
610	**STVFBEDGEL**	V/K	0	–	–	Length dependence	1
611	**STVFBEDGEW**	V/K	0	–	–	Width dependence	1
612	**STVFBEDGELW**	V/K	0	–	–	Area dependence	1
613	**POSTVFBEDGE**	V/K	$5 \cdot 10^{-4}$	–	–	Binning: geom. independent part	1
614	**PLSTVFBEDGE**	V/K	0	–	–	Binning: length dependence	1
615	**PWSTVFBEDGE**	V/K	0	–	–	Binning: width dependence	1
616	**PLWSTVFBEDGE**	V/K	0	–	–	Binning: area dependence	1
617	**DPHIBEDGE**	V	0	–	–	Offset of φ_B for edge transistors	0
618	**DPHIBEDGEO**	V	0	–	–	Geometry independent part	1
619	**DPHIBEDGEL**	V	0	–	–	Length dependence	1
620	**DPHIBEDGELEXP**	–	1	–	–	Exponent for length dependence	1

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
621	**DPHIBEDGEW**	–	0	–	–	Width dependence	1
622	**DPHIBEDGELW**	–	0	–	–	Area dependence	1
623	**PODPHIBEDGE**	V	0	–	–	Binning: geom. independent part	1
624	**PLDPHIBEDGE**	V	0	–	–	Binning: length dependence	1
625	**PWDPHIBEDGE**	V	0	–	–	Binning: width dependence	1
626	**PLWDPHIBEDGE**	V	0	–	–	Binning: area dependence	1
627	**NEFFEDGE**	m^{-3}	$5 \cdot 10^{23}$	10^{20}	10^{26}	Effective substrate doping of edge transistors	0
628	**NSUBEDGEO**	m^{-3}	$5 \cdot 10^{23}$	10^{20}	–	Geometry independent substrate doping	1
629	**NSUBEDGEL**	–	0	–	–	Length dependence	1
630	**NSUBEDGELEXP**	–	1	–	–	Exponent for length dependence	1
631	**NSUBEDGEW**	–	0	–	–	Width dependence of edge transistor substrate doping	1
632	**NSUBEDGELW**	–	0	–	–	Area dependence	1
633	**PONEFFEDGE**	m^{-3}	$5 \cdot 10^{23}$	–	–	Binning: geom. independent part	1
634	**PLNEFFEDGE**	m^{-3}	0	–	–	Binning: length dependence	1
635	**PWNEFFEDGE**	m^{-3}	0	–	–	Binning: width dependence	1
636	**PLWNEFFEDGE**	m^{-3}	0	–	–	Binning: area dependence	1
637	**CTEDGE**	–	0	0	–	Interface states factor of edge transistors	0
638	**CTEDGEO**	–	0	–	–	Geometry-independent part	1
639	**CTEDGEL**	–	0	–	–	Length dependence	1
640	**CTEDGELEXP**	–	1	–	–	Exponent for length dependence	1
641	**POCTEDGE**	–	0	–	–	Binning: geom. independent part	1
642	**PLCTEDGE**	–	0	–	–	Binning: length dependence	1
643	**PWCTEDGE**	–	0	–	–	Binning: width dependence	1
644	**PLWCTEDGE**	–	0	–	–	Binning: area dependence	1
645	**BETNEDGE**	$\mathrm{m}^2/\mathrm{V/s}$	$6 \cdot 10^{-4}$	0	–	Product of channel aspect ratio and zero-field mobility of edge transistors at **TR**	0
646	**FBETEDGE**	–	0	–	–	Length dependence	1
647	**LPEDGE**	m	10^{-8}	10^{-10}	–	Exponent for length dependence	1
648	**BETEDGEW**	–	0	–	–	Width scaling coefficient	1
649	**POBETNEDGE**	$\mathrm{m}^2/\mathrm{V/s}$	$3 \cdot 10^{-2}$	–	–	Binning: geom. independent part	1
650	**PLBETNEDGE**	$\mathrm{m}^2/\mathrm{V/s}$	0	–	–	Binning: length dependence	1
651	**PWBETNEDGE**	$\mathrm{m}^2/\mathrm{V/s}$	0	–	–	Binning: width dependence	1
652	**PLWBETNEDGE**	$\mathrm{m}^2/\mathrm{V/s}$	0	–	–	Binning: area dependence	1
653	**STBETEDGE**	–	1	–	–	Temperature dependence of **BETNEDGE**	0

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
654	**STBETEDGEO**	–	1	–	–	Geometry independent part	1
655	**STBETEDGEL**	–	0	–	–	Length dependence	1
656	**STBETEDGEW**	–	0	–	–	Width dependence	1
657	**STBETEDGELW**	–	0	–	–	Area dependence	1
658	**POSTBETEDGE**	–	1	–	–	Binning: geom. independent part	1
659	**PLSTBETEDGE**	–	0	–	–	Binning: length dependence	1
660	**PWSTBETEDGE**	–	0	–	–	Binning: width dependence	1
661	**PLWSTBETEDGE**	–	0	–	–	Binning: area dependence	1
662	**PSCEEDGE**	–	0	0	–	Subthreshold slope coefficient for short channel edge transistors	0
663	**PSCEEDGEL**	–	0	–	–	Length dependence	1
664	**PSCEEDGELEXP**	–	2	–	–	Exponent for length dependence	1
665	**PSCEEDGEW**	–	0	–	–	Width dependence	1
666	**POPSCEEDGE**	–	0	–	–	Binning: geom. independent part	1
667	**PLPSCEEDGE**	–	0	–	–	Binning: length dependence	1
668	**PWPSCEEDGE**	–	0	–	–	Binning: width dependence	1
669	**PLWPSCEEDGE**	–	0	–	–	Binning: area dependence	1
670	**PSCEBEDGE**	V^{-1}	0	0	1	Bulk voltage dependence of subthreshold slope coefficient for short channel edge transistors	0
671	**PSCEBEDGEO**	V^{-1}	0	0	1	Geometry-independent parameter	1
672	**POPSCEBEDGE**	V^{-1}	0	–	–	Binning: geom. independent part	1
673	**PLPSCEBEDGE**	V^{-1}	0	–	–	Binning: length dependence	1
674	**PWPSCEBEDGE**	V^{-1}	0	–	–	Binning: width dependence	1
675	**PLWPSCEBEDGE**	V^{-1}	0	–	–	Binning: area dependence	1
676	**PSCEDEDGE**	V^{-1}	0	0	–	Drain voltage dependence of subthreshold slope coefficient for short channel edge transistors	0
677	**PSCEDEDGEO**	V^{-1}	0	0	–	Geometry-independent parameter	1
678	**POPSCEDEDGE**	V^{-1}	0	–	–	Binning: geom. independent part	1
679	**PLPSCEDEDGE**	V^{-1}	0	–	–	Binning: length dependence	1
680	**PWPSCEDEDGE**	V^{-1}	0	–	–	Binning: width dependence	1
681	**PLWPSCEDEDGE**	V^{-1}	0	–	–	Binning: area dependence	1
682	**CFEDGE**	–	0	0	–	DIBL of edge transistors	0
683	**CFEDGEL**	–	0	–	–	Length dependence	1
684	**CFEDGELEXP**	–	2	–	–	Exponent for length dependence	1
685	**CFEDGEW**	–	0	–	–	Width dependence	1
686	**POCFEDGE**	–	0	–	–	Binning: geom. independent part	1
687	**PLCFEDGE**	–	0	–	–	Binning: length dependence	1

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
688	**PWCFEDGE**	–	0	–	–	Binning: width dependence	1
689	**PLWCFEDGE**	–	0	–	–	Binning: area dependence	1
690	**CFBEDGE**	V^{-1}	0	0	1	Bulk voltage dependence parameter of DIBL-parameter of edge transistors	0
691	**CFBEDGEO**	V^{-1}	0	0	1	Geometry-independent parameter	1
692	**POCFBEDGE**	V^{-1}	0	–	–	Binning: geom. independent part	1
693	**PLCFBEDGE**	V^{-1}	0	–	–	Binning: length dependence	1
694	**PWCFBEDGE**	V^{-1}	0	–	–	Binning: width dependence	1
695	**PLWCFBEDGE**	V^{-1}	0	–	–	Binning: area dependence	1
696	**CFDEDGE**	V^{-1}	0	0	–	Drain voltage dependence parameter of DIBL-parameter of edge transistors	0
697	**CFDEDGEO**	V^{-1}	0	0	–	Geometry-independent parameter	1
698	**POCFDEDGE**	V^{-1}	0	–	–	Binning: geom. independent part	1
699	**PLCFDEDGE**	V^{-1}	0	–	–	Binning: length dependence	1
700	**PWCFDEDGE**	V^{-1}	0	–	–	Binning: width dependence	1
701	**PLWCFDEDGE**	V^{-1}	0	–	–	Binning: area dependence	1
702	**FNTEDGE**	–	1	0	–	Thermal noise coefficient of edge transistors	0
703	**FNTEDGEO**	–	1	0	–	Geometry-independent parameter	1
704	**NFAEDGE**	V^{-1}/m^4	$4 \cdot 10^{24}$	0	–	First coefficient of flicker noise of edge transistors	0
705	**NFAEDGELW**	V^{-1}/m^4	$8 \cdot 10^{22}$	0	–	Area dependence	1
706	**PONFAEDGE**	V^{-1}/m^4	$8 \cdot 10^{22}$	–	–	Binning: geom. independent part	1
707	**PLNFAEDGE**	V^{-1}/m^4	0	–	–	Binning: length dependence	1
708	**PWNFAEDGE**	V^{-1}/m^4	0	–	–	Binning: width dependence	1
709	**PLWNFAEDGE**	V^{-1}/m^4	0	–	–	Binning: area dependence	1
710	**NFBEDGE**	V^{-1}/m^2	$1.5 \cdot 10^9$	0	–	Second coefficient of flicker noise of edge transistors	0
711	**NFBEDGELW**	V^{-1}/m^2	$3 \cdot 10^7$	0	–	Area dependence	1
712	**PONFBEDGE**	V^{-1}/m^2	$3 \cdot 10^7$	–	–	Binning: geom. independent part	1
713	**PLNFBEDGE**	V^{-1}/m^2	0	–	–	Binning: length dependence	1
714	**PWNFBEDGE**	V^{-1}/m^2	0	–	–	Binning: width dependence	1
715	**PLWNFBEDGE**	V^{-1}/m^2	0	–	–	Binning: area dependence	1
716	**NFCEDGE**	V^{-1}	0	0	–	Third coefficient of flicker noise of edge transistors	0
717	**NFCEDGELW**	V^{-1}	0	0	–	Area dependence	1

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No.	Name	Unit	Default	Min.	Max.	Description	Geo.
718	**PONFCEDGE**	V^{-1}	0	–	–	Binning: geom. independent part	1
719	**PLNFCEDGE**	V^{-1}	0	–	–	Binning: length dependence	1
720	**PWNFCEDGE**	V^{-1}	0	–	–	Binning: width dependence	1
721	**PLWNFCEDGE**	V^{-1}	0	–	–	Binning: area dependence	1
722	**EFEDGE**	–	1	0	–	Flicker noise frequency exponent of edge transistors	0
723	**EFEDGEO**	–	1	0	–	Geometry-independent parameter	1

2.5.3 Parameters for self heating

The parameters for self heating are listed below. They are only available in the self heating version of the model. The last column—labeled '**Geo.**'—shows for which value of **SWGEO** the parameter is used.

No.	Name	Unit	Default	Min.	Max.	Description	Geo.
0	**RTH**	K/W	0	0	–	Thermal resistance	0
1	**RTHO**	K/W	0	–	–	Geometry independent part	1
2	**RTHW1**	K/W	0	–	–	Width dependence	1
3	**RTHW2**	–	0	–	–	Offset in width dependence	1
4	**RTHLW**	–	0	–	–	Length-correction to width dependence	1
5	**PORTH**	K/W	0	–	–	Binning: geom. independent part	1
6	**PLRTH**	K/W	0	–	–	Binning: length dependence	1
7	**PWRTH**	K/W	0	–	–	Binning: width dependence	1
8	**PLWRTH**	K/W	0	–	–	Binning: area dependence	1
9	**CTH**	J/K	0	0	–	Thermal capacitance	0
10	**CTHO**	J/K	0	–	–	Geometry independent part	1
11	**CTHW1**	J/K	0	–	–	Width dependence	1
12	**CTHW2**	–	0	–	–	Offset in width dependence	1
13	**CTHLW**	–	0	–	–	Length-correction to width dependence	1
14	**POCTH**	J/K	0	–	–	Binning: geom. independent part	1
15	**PLCTH**	J/K	0	–	–	Binning: length dependence	1
16	**PWCTH**	J/K	0	–	–	Binning: width dependence	1
17	**PLWCTH**	J/K	0	–	–	Binning: area dependence	1
18	**STRTH**	–	0	–	–	Temperature dependence of **RTH**	0
19	**STRTHO**	–	0	–	–	Geometry-independent parameter	1
20	**POSTRTH**	–	0	–	–	Binning: geom. independent part	1
21	**PLSTRTH**	–	0	–	–	Binning: length dependence	1
22	**PWSTRTH**	–	0	–	–	Binning: width dependence	1
23	**PLWSTRTH**	–	0	–	–	Binning: area dependence	1

2.5.4 Parameters for NQS

The parameters for non-quasi-static effects are listed below. They are only available in the NQS-version of the model. The last column—labeled ‘**Geo.**’—shows for which value of **SWGEO** the parameter is used.

No.	**Name**	**Unit**	**Default**	**Min.**	**Max.**	**Description**	**Geo.**
0	**SWNQS**	–	0	0	9	Switch for NQS effects / number of collocation points	0, 1
1	**MUNQS**	–	1	0	–	Relative mobility for NQS modeling	0
2	**MUNQSO**	–	1	0	–	Geometry-independent parameter	1
3	**POMUNQS**	–	1	–	–	Binning: geom. independent part	1
4	**PLMUNQS**	–	0	–	–	Binning: length dependence	1
5	**PWMUNQS**	–	0	–	–	Binning: width dependence	1
6	**PLWMUNQS**	–	0	–	–	Binning: area dependence	1

2.5.5 Parameters for stress model

The stress model of BSIM4.4.0 has been adopted in PSP with as little modifications as possible. Parameter names have been copied, but they have been subjected to PSP conventions by replacing every zero by an ‘**O**’. Moreover, the parameters **STK2** and **LODK2** are not available in PSP. Except for these changes, stress parameters determined for BSIM can be directly applied in PSP. Some trivial conversion of parameters BSIM→PSP is still necessary, see [2].

The parameters in this section are part of PSP’s global parameter set (both geometrical and binning).

No.	Name	Unit	Default	Min.	Max.	Description	Geo.
0	**SAREF**	m	10^{-6}	10^{-9}	–	Reference distance between OD edge to Poly from one side	1
1	**SBREF**	m	10^{-6}	10^{-9}	–	Reference distance between OD edge to Poly from other side	1
2	**WLOD**	m	0	–	–	Width parameter	1
3	**KUO**	m	0	–	–	Mobility degradation/enhancement coefficient	1
4	**KVSAT**	m	0	-1	1	Saturation velocity degradation/enhancement parameter	1
5	**KVSATAC**	m	**KVSAT**	-1	1	Saturation velocity degradation/enhancement parameter for charge model with **SWQSAT**=1	1
6	**TKUO**	–	0	–	–	Temperature coefficient of **KUO**	1
7	**LKUO**	$\mathrm{m}^{\mathbf{LLODKUO}}$	0	–	–	Length dependence of **KUO**	1
8	**WKUO**	$\mathrm{m}^{\mathbf{WLODKUO}}$	0	–	–	Width dependence of **KUO**	1
9	**PKUO**	$\mathrm{m}^{\mathbf{LLODKUO}+\mathbf{WLODKUO}}$	0	–	–	Cross-term dependence of **KUO**	1
10	**LLODKUO**	–	0	0	–	Length parameter for mobility stress effect	1
11	**WLODKUO**	–	0	0	–	Width parameter for mobility stress effect	1
12	**KVTHO**	Vm	0	–	–	Threshold shift parameter	1
13	**LKVTHO**	$\mathrm{m}^{\mathbf{LLODVTH}}$	0	–	–	Length dependence of **KVTHO**	1
14	**WKVTHO**	$\mathrm{m}^{\mathbf{WLODVTH}}$	0	–	–	Width dependence of **KVTHO**	1
15	**PKVTHO**	$\mathrm{m}^{\mathbf{LLODVTH}+\mathbf{WLODVTH}}$	0	–	–	Cross-term dependence of **KVTHO**	1
16	**LLODVTH**	–	0	0	–	Length parameter for threshold voltage stress effect	1
17	**WLODVTH**	–	0	0	–	Width parameter for threshold voltage stress effect	1
18	**STETAO**	m	0	–	–	ETAO shift factor related to threshold voltage change	1
19	**LODETAO**	–	1	0	–	ETAO shift modification factor	1

2.5.6 Parameters for well proximity effect model

The WPE model of BSIM4.5.0 has been adopted in PSP with as little modifications as possible. Parameter names have been copied, but they have been subjected to PSP conventions by replacing every zero by an '**O**'. Moreover, the parameter **K2WE** is not available in PSP. Except for some trivial conversion of parameters BSIM→PSP [2], WPE parameters from BSIM can be used directly in PSP. The WPE parameters have both geometrical and binning rules included as explained in Section 3.7.2. The last column—labeled '**Geo.**'—shows for which value of **SWGEO** the parameter is used.

No.	Name	Unit	Default	Min.	Max.	Description	Geo.
0	**SCREF**	m	$1 \cdot 10^{-6}$	0	–	Distance between OD-edge and well edge of a reference device	1
1	**WEB**	–	0	–	–	Coefficient for **SCB**	1
2	**WEC**	–	0	–	–	Coefficient for **SCC**	1
3	**KVTHOWEO**	–	0	–	–	Geometry independent threshold shift parameter	1
4	**KVTHOWEL**	–	0	–	–	Length dependence	1
5	**KVTHOWEW**	–	0	–	–	Width dependence	1
6	**KVTHOWELW**	–	0	–	–	Area dependence	1
7	**KUOWEO**	–	0	–	–	Geometry independent mobility degradation factor	1
8	**KUOWEL**	–	0	–	–	Length dependence	1
9	**KUOWEW**	–	0	–	–	Width dependence	1
10	**KUOWELW**	–	0	–	–	Area dependence	1

2.5.7 Parameters for source-bulk and drain-bulk junction model

The JUNCAP2 parameters are part of both the global and the local parameter sets. The last column of **Asym.** shows for which value of **SWJUNASYM** the listed parameter is enabled: i.e., when **SWJUNASYM** $= 0$, parameters No. 3-45 are used for both source-bulk and drain-bulk junctions and parameters No. 46-88 are ignored; when **SWJUNASYM** $= 1$, parameters No. 3-45 are used for source-bulk junction and No. 46-88 are used for drain-bulk junction; parameters No. 0-2 are used in both situations.

No.	Name	Unit	Default	Min.	Max.	Description	Asym.
0	**TRJ**	°C	21	$T_{\rm min}$	–	Reference temperature	0, 1
1	**SWJUNEXP**	–	0	0	1	Flag for JUNCAP2 Express; 0 $\leftrightarrow$ full JUNCAP2 model, 1 $\leftrightarrow$ Express model	0, 1
2	**IFACTOR**	–	1	0	–	Multiplier for current	0, 1
3	**CFACTOR**	–	1	0	–	Multiplier for depletion capacitance	0, 1
4	**IMAX**	A	10^3	10^{-12}	–	Maximum current up to which forward current behaves exponentially	0, 1
5	**FREV**	–	10^3	10^3	10^{10}	Coefficient for reverse breakdown current limitation	0, 1
				Capacitance Parameters			
6	**CJORBOT**	F/m^2	10^{-3}	10^{-12}	–	Zero-bias capacitance per unit-of-area of bottom component for source-bulk junction	0, 1
7	**CJORSTI**	F/m	10^{-9}	10^{-18}	–	Zero-bias capacitance per unit-of-length of STI-edge component for source-bulk junction	0, 1
8	**CJORGAT**	F/m	10^{-9}	10^{-18}	–	Zero-bias capacitance per unit-of-length of gate-edge component for source-bulk junction	0, 1
9	**VBIRBOT**	V	1	$V_{\rm bi,low}$	–	Built-in voltage at the reference temperature of bottom component for source-bulk junction	0, 1
10	**VBIRSTI**	V	1	$V_{\rm bi,low}$	–	Built-in voltage at the reference temperature of STI-edge component for source-bulk junction	0, 1
11	**VBIRGAT**	V	1	$V_{\rm bi,low}$	–	Built-in voltage at the reference temperature of gate-edge component for source-bulk junction	0, 1
12	**PBOT**	–	0.5	0.05	0.95	Grading coefficient of bottom component for source-bulk junction	0, 1
13	**PSTI**	–	0.5	0.05	0.95	Grading coefficient of STI-edge component for source-bulk junction	0, 1

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No.	Name	Unit	Default	Min.	Max.	Description	Asym.
14	**PGAT**	–	0.5	0.05	0.95	Grading coefficient of gate-edge component for source-bulk junction	0, 1
						Ideal-current Parameters	
15	**PHIGBOT**	V	1.16	–	–	Zero-temperature bandgap voltage of bottom component for source-bulk junction	0, 1
16	**PHIGSTI**	V	1.16	–	–	Zero-temperature bandgap voltage of STI-edge component for source-bulk junction	0, 1
17	**PHIGGAT**	V	1.16	–	–	Zero-temperature bandgap voltage of gate-edge component for source-bulk junction	0, 1
18	**IDSATRBOT**	A/m^2	10^{-12}	0	–	Saturation current density at the reference temperature of bottom component for source-bulk junction	0, 1
19	**IDSATRSTI**	A/m	10^{-18}	0	–	Saturation current density at the reference temperature of STI-edge component for source-bulk junction	0, 1
20	**IDSATRGAT**	A/m	10^{-18}	0	–	Saturation current density at the reference temperature of gate-edge component for source-bulk junction	0, 1
						Shockley-Read-Hall Parameters	
21	**CSRHBOT**	A/m^3	10^2	0	–	Shockley-Read-Hall prefactor of bottom component for source-bulk junction	0, 1
22	**CSRHSTI**	A/m^2	10^{-4}	0	–	Shockley-Read-Hall prefactor of STI-edge component for source-bulk junction	0, 1
23	**CSRHGAT**	A/m^2	10^{-4}	0	–	Shockley-Read-Hall prefactor of gate-edge component for source-bulk junction	0, 1
24	**XJUNSTI**	m	10^{-7}	10^{-9}	–	Junction depth of STI-edge component for source-bulk junction	0, 1
25	**XJUNGAT**	m	10^{-7}	10^{-9}	–	Junction depth of gate-edge component for source-bulk junction	0, 1
						Trap-assisted Tunneling Parameters	
26	**CTATBOT**	A/m^3	10^2	0	–	Trap-assisted tunneling prefactor of bottom component for source-bulk junction	0, 1

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No.	Name	Unit	Default	Min.	Max.	Description	Asym.
27	**CTATSTI**	A/m^2	10^{-4}	0	–	Trap-assisted tunneling prefactor of STI-edge component for source-bulk junction	0, 1
28	**CTATGAT**	A/m^2	10^{-4}	0	–	Trap-assisted tunneling prefactor of gate-edge component for source-bulk junction	0, 1
29	**MEFFTATBOT**	–	0.25	.01	–	Effective mass (in units of m_0) for trap-assisted tunneling of bottom component for source-bulk junction	0, 1
30	**MEFFTATSTI**	–	0.25	.01	–	Effective mass (in units of m_0) for trap-assisted tunneling of STI-edge component for source-bulk junction	0, 1
31	**MEFFTATGAT**	–	0.25	.01	–	Effective mass (in units of m_0) for trap-assisted tunneling of gate-edge component for source-bulk junction	0, 1
						Band-to-band Tunneling Parameters	
32	**CBBTBOT**	AV^{-3}	10^{-12}	0	–	Band-to-band tunneling prefactor of bottom component for source-bulk junction	0, 1
33	**CBBTSTI**	AV^{-3}m	10^{-18}	0	–	Band-to-band tunneling prefactor of STI-edge component for source-bulk junction	0, 1
34	**CBBTGAT**	AV^{-3}m	10^{-18}	0	–	Band-to-band tunneling prefactor of gate-edge component for source-bulk junction	0, 1
35	**FBBTRBOT**	Vm^{-1}	10^9	–	–	Normalization field at the reference temperature for band-to-band tunneling of bottom component for source-bulk junction	0, 1
36	**FBBTRSTI**	Vm^{-1}	10^9	–	–	Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for source-bulk junction	0, 1
37	**FBBTRGAT**	Vm^{-1}	10^9	–	–	Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for source-bulk junction	0, 1
38	**STFBBTBOT**	K^{-1}	-10^{-3}	–	–	Temperature scaling parameter for band-to-band tunneling of bottom component for source-bulk junction	0, 1
39	**STFBBTSTI**	K^{-1}	-10^{-3}	–	–	Temperature scaling parameter for band-to-band tunneling of STI-edge component for source-bulk junction	0, 1

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No.	Name	Unit	Default	Min.	Max.	Description	Asym.
40	**STFBBTGAT**	K^{-1}	-10^{-3}	–	–	Temperature scaling parameter for band-to-band tunneling of gate-edge component for source-bulk junction	0, 1
				Avalanche and Breakdown Parameters			
41	**VBRBOT**	V	10	0.1	–	Breakdown voltage of bottom component for source-bulk junction	0, 1
42	**VBRSTI**	V	10	0.1	–	Breakdown voltage of STI-edge component for source-bulk junction	0, 1
43	**VBRGAT**	V	10	0.1	–	Breakdown voltage of gate-edge component for source-bulk junction	0, 1
44	**PBRBOT**	V	4	0.1	–	Breakdown onset tuning parameter of bottom component for source-bulk junction	0, 1
45	**PBRSTI**	V	4	0.1	–	Breakdown onset tuning parameter of STI-edge component for source-bulk junction	0, 1
46	**PBRGAT**	V	4	0.1	–	Breakdown onset tuning parameter of gate-edge component for source-bulk junction	0, 1
				JUNCAP Express Parameters			
47	**VJUNREF**	V	2.5	0.5	–	Typical maximum source-bulk junction voltage; usually about $2 \cdot V_{\mathrm{sup}}$	0, 1
48	**FJUNQ**	V	0.03	0	–	Fraction below which source-bulk junction capacitance components are neglected	0, 1
				Capacitance Parameters			
49	**CJORBOTD**	$\mathrm{F/m^2}$	10^{-3}	10^{-12}	–	Zero-bias capacitance per unit-of-area of bottom component for drain-bulk junction	1
50	**CJORSTID**	F/m	10^{-9}	10^{-18}	–	Zero-bias capacitance per unit-of-length of STI-edge component for drain-bulk junction	1
51	**CJORGATD**	F/m	10^{-9}	10^{-18}	–	Zero-bias capacitance per unit-of-length of gate-edge component for drain-bulk junction	1
52	**VBIRBOTD**	V	1	$V_{\mathrm{bi,low}}$	–	Built-in voltage at the reference temperature of bottom component for drain-bulk junction	1
53	**VBIRSTID**	V	1	$V_{\mathrm{bi,low}}$	–	Built-in voltage at the reference temperature of STI-edge component for drain-bulk junction	1

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No.	Name	Unit	Default	Min.	Max.	Description	Asym.
54	**VBIRGATD**	V	1	$V_{\mathrm{bi,low}}$	–	Built-in voltage at the reference temperature of gate-edge component for drain-bulk junction	1
55	**PBOTD**	–	0.5	0.05	0.95	Grading coefficient of bottom component for drain-bulk junction	1
56	**PSTID**	–	0.5	0.05	0.95	Grading coefficient of STI-edge component for drain-bulk junction	1
57	**PGATD**	–	0.5	0.05	0.95	Grading coefficient of gate-edge component for drain-bulk junction	1
				Ideal-current Parameters			
58	**PHIGBOTD**	V	1.16	–	–	Zero-temperature bandgap voltage of bottom component for drain-bulk junction	1
59	**PHIGSTID**	V	1.16	–	–	Zero-temperature bandgap voltage of STI-edge component for drain-bulk junction	1
60	**PHIGGATD**	V	1.16	–	–	Zero-temperature bandgap voltage of gate-edge component for drain-bulk junction	1
61	**IDSATRBOTD**	A/m^2	10^{-12}	0	–	Saturation current density at the reference temperature of bottom component for drain-bulk junction	1
62	**IDSATRSTID**	A/m	10^{-18}	0	–	Saturation current density at the reference temperature of STI-edge component for drain-bulk junction	1
63	**IDSATRGATD**	A/m	10^{-18}	0	–	Saturation current density at the reference temperature of gate-edge component for drain-bulk junction	1
				Shockley-Read-Hall Parameters			
64	**CSRHBOTD**	A/m^3	10^{2}	0	–	Shockley-Read-Hall prefactor of bottom component for drain-bulk junction	1
65	**CSRHSTID**	A/m^2	10^{-4}	0	–	Shockley-Read-Hall prefactor of STI-edge component for drain-bulk junction	1
66	**CSRHGATD**	A/m^2	10^{-4}	0	–	Shockley-Read-Hall prefactor of gate-edge component for drain-bulk junction	1
67	**XJUNSTID**	m	10^{-7}	10^{-9}	–	Junction depth of STI-edge component for drain-bulk junction	1
68	**XJUNGATD**	m	10^{-7}	10^{-9}	–	Junction depth of gate-edge component for drain-bulk junction	1
				Trap-assisted Tunneling Parameters			

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No.	Name	Unit	Default	Min.	Max.	Description	Asym.
69	**CTATBOTD**	A/m^3	10^2	0	–	Trap-assisted tunneling prefactor of bottom component for drain-bulk junction	1
70	**CTATSTID**	A/m^2	10^{-4}	0	–	Trap-assisted tunneling prefactor of STI-edge component for drain-bulk junction	1
71	**CTATGATD**	A/m^2	10^{-4}	0	–	Trap-assisted tunneling prefactor of gate-edge component for drain-bulk junction	1
72	**MEFFTATBOTD**	–	0.25	.01	–	Effective mass (in units of m_0) for trap-assisted tunneling of bottom component for drain-bulk junction	1
73	**MEFFTATSTID**	–	0.25	.01	–	Effective mass (in units of m_0) for trap-assisted tunneling of STI-edge component for drain-bulk junction	1
74	**MEFFTATGATD**	–	0.25	.01	–	Effective mass (in units of m_0) for trap-assisted tunneling of gate-edge component for drain-bulk junction	1
						Band-to-band Tunneling Parameters	
75	**CBBTBOTD**	AV^{-3}	10^{-12}	0	–	Band-to-band tunneling prefactor of bottom component for drain-bulk junction	1
76	**CBBTSTID**	AV^{-3}m	10^{-18}	0	–	Band-to-band tunneling prefactor of STI-edge component for drain-bulk junction	1
77	**CBBTGATD**	AV^{-3}m	10^{-18}	0	–	Band-to-band tunneling prefactor of gate-edge component for drain-bulk junction	1
78	**FBBTRBOTD**	Vm^{-1}	10^9	–	–	Normalization field at the reference temperature for band-to-band tunneling of bottom component for drain-bulk junction	1
79	**FBBTRSTID**	Vm^{-1}	10^9	–	–	Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for drain-bulk junction	1
80	**FBBTRGATD**	Vm^{-1}	10^9	–	–	Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for drain-bulk junction	1
81	**STFBBTBOTD**	K^{-1}	-10^{-3}	–	–	Temperature scaling parameter for band-to-band tunneling of bottom component for drain-bulk junction	1
82	**STFBBTSTID**	K^{-1}	-10^{-3}	–	–	Temperature scaling parameter for band-to-band tunneling of STI-edge component for drain-bulk junction	1

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No.	Name	Unit	Default	Min.	Max.	Description	Asym.
83	**STFBBTGATD**	K^{-1}	-10^{-3}	–	–	Temperature scaling parameter for band-to-band tunneling of gate-edge component for drain-bulk junction	1
				Avalanche and Breakdown Parameters			
84	**VBRBOTD**	V	10	0.1	–	Breakdown voltage of bottom component for drain-bulk junction	1
85	**VBRSTID**	V	10	0.1	–	Breakdown voltage of STI-edge component for drain-bulk junction	1
86	**VBRGATD**	V	10	0.1	–	Breakdown voltage of gate-edge component for drain-bulk junction	1
87	**PBRBOTD**	V	4	0.1	–	Breakdown onset tuning parameter of bottom component for drain-bulk junction	1
88	**PBRSTID**	V	4	0.1	–	Breakdown onset tuning parameter of STI-edge component for drain-bulk junction	1
89	**PBRGATD**	V	4	0.1	–	Breakdown onset tuning parameter of gate-edge component for drain-bulk junction	1
				JUNCAP Express Parameters			
90	**VJUNREFD**	V	2.5	0.5	–	Typical maximum drain-bulk junction voltage; usually about $2 \cdot V_{\mathrm{sup}}$	1
91	**FJUNQD**	V	0.03	0	–	Fraction below which drain-bulk junction capacitance components are neglected	1

2.5.8 Parameters for parasitic resistances

The parameters for parasitic resistances are listed in the table below. The last column—labeled ‘**Geo.**’—shows for which value of **SWGEO** the parameter is used.

No.	Name	Unit	Default	Min.	Max.	Description	Geo.
0	**RG**	Ω	0	0	–	Gate resistance R_{gate}	0
1	**RGO**	Ω	0	–	–	Gate resistance R_{gate}	1
2	**RINT**	Ω·m^2	0	0	–	Contact resistance between silicide and poly	1
3	**RVPOLY**	Ω·m^2	0	0	–	Vertical poly resistance	1
4	**RSHG**	Ω/□	0	0	–	Gate electrode diffusion sheet resistance	1
5	**DLSIL**	m	0	–	–	Silicide extension over the physical gate length	1
6	**RSE**	Ω	0	0	–	External source resistance R_{source}	0
7	**RSH**	Ω/□	0	0	–	Sheet resistance of source diffusion	1
8	**RDE**	Ω	0	0	–	External drain resistance R_{drain}	0
9	**RSHD**	Ω/□	0	0	–	Sheet resistance of drain diffusion	1
10	**RBULK**	Ω	0	0	–	Bulk resistance R_{bulk}	0
11	**RBULKO**	Ω	0	0	–	Bulk resistance R_{bulk}	1
12	**RWELL**	Ω	0	0	–	Well resistance R_{well}	0
13	**RWELLO**	Ω	0	0	–	Well resistance R_{well}	1
14	**RJUNS**	Ω	0	0	–	Source-side bulk resistance R_{juns}	0
15	**RJUNSO**	Ω	0	0	–	Source-side bulk resistance R_{juns}	1
16	**RJUND**	Ω	0	0	–	Drain-side bulk resistance R_{jund}	0
17	**RJUNDO**	Ω	0	0	–	Drain-side bulk resistance R_{jund}	1

Section 3

Geometry Dependence and Other Effects

3.1 Introduction

The physical geometry scaling rules of PSP (Section 3.3) have been developed to give a good description over the whole geometry range of CMOS technologies. As an alternative, the binning-rules can be used (Section 3.4) to allow for a more phenomenological geometry dependency. (Note that the user can mix the two options; the geometrical scaling rules and the binning scaling rules at the same time.) The result is a local parameter set (for a transistor of the specified L and W), which is fed into the local model.

Stress and well proximity effects are included in PSP. Use of the stress model (Section 3.6) and/or well proximity effect model (Section 3.7) leads to modification of some of the local parameters calculated from the geometrical or/and binning scaling rules.

3.2 Effective Length and Width

$$L_{\mathrm{EN}} = 10^{-6} \tag{3.1}$$

$$W_{\mathrm{EN}} = 10^{-6} \tag{3.2}$$

$$A_{\mathrm{EN}} = 10^{-12} \tag{3.3}$$

$$W_{\mathrm{f}} = \frac{W}{\mathbf{NF}} \tag{3.4}$$

$$\Delta L_{\mathrm{PS}} = \mathbf{LVARO} \cdot \left(1 + \mathbf{LVARL} \cdot \frac{L_{\mathrm{EN}}}{L}\right) \cdot \left(1 + \mathbf{LVARW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{f}}}\right) \tag{3.5}$$

$$\Delta W_{\mathrm{OD}} = \mathbf{WVARO} \cdot \left(1 + \mathbf{WVARL} \cdot \frac{L_{\mathrm{EN}}}{L}\right) \cdot \left(1 + \mathbf{WVARW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{f}}}\right) \tag{3.6}$$

$$L_{\mathrm{E}} = L - \Delta L = L + \Delta L_{\mathrm{PS}} - 2 \cdot \mathbf{LAP} \tag{3.7}$$

$$W_{\mathrm{E}} = W_{\mathrm{f}} - \Delta W = W_{\mathrm{f}} + \Delta W_{\mathrm{OD}} - 2 \cdot \mathbf{WOT} \tag{3.8}$$

$$A_{\mathrm{E}} = L_{\mathrm{E}} \cdot W_{\mathrm{E}} \tag{3.9}$$

$$L_{\mathrm{E,CV}} = L + \Delta L_{\mathrm{PS}} - 2 \cdot \mathbf{LAP} + \mathbf{DLQ} \tag{3.10}$$

$$W_{\mathrm{E,CV}} = W_{\mathrm{f}} + \Delta W_{\mathrm{OD}} - 2 \cdot \mathbf{WOT} + \mathbf{DWQ} \tag{3.11}$$

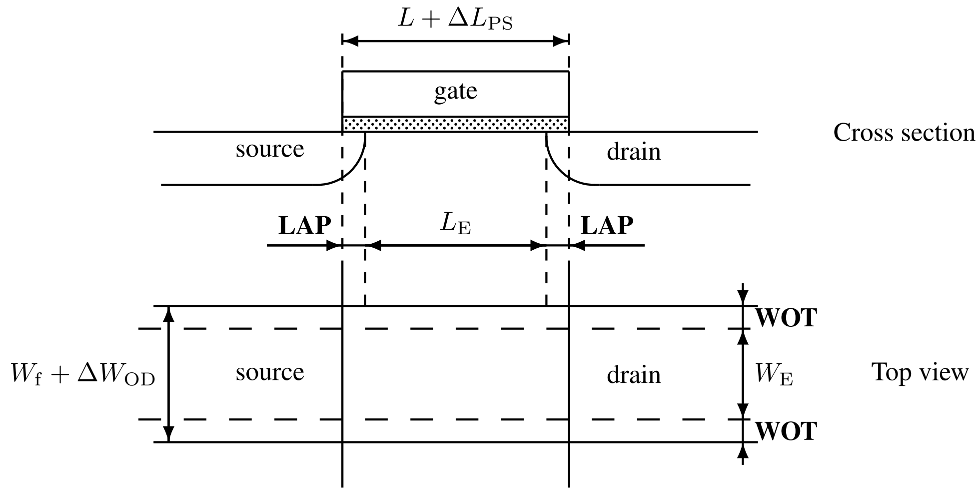

Figure 3.1: Specification of the dimensions of a MOS transistor

$$A_{\mathrm{G,CV}} = L_{\mathrm{E,CV}} \cdot W_{\mathrm{E,CV}} \tag{3.12}$$

$$L_{\mathrm{G,CV}} = L + \Delta L_{\mathrm{PS}} + \mathbf{DLQ} \tag{3.13}$$

$$W_{\mathrm{G,CV}} = W_{\mathrm{f}} + \Delta W_{\mathrm{OD}} + \mathbf{DWQ} \tag{3.14}$$

Note: If the calculated L_{E}, W_{E}, $L_{\mathrm{E,CV}}$, $W_{\mathrm{E,CV}}$, $L_{\mathrm{G,CV}}$, or $W_{\mathrm{G,CV}}$ is smaller than 1 nm (10^{-9} m), the value is clipped to this lower bound of 1 nm.

3.3 Physical Scaling Rules

The physical scaling rules to calculate the local parameters from a global parameter set are given in this section.

Note:

- After calculation of the local parameters (and possible application of the stress equations in Section 3.6), clipping is applied according to Section 2.5.2.
- The geometrical scaling equations are *only* calculated when **SWGEO** $= 1$.

Flat-Band Voltage Parameters

$$\mathbf{VFB} = \mathbf{VFBO} + \mathbf{VFBL} \cdot \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^{\mathbf{VFBLEXP}} + \mathbf{VFBW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{VFBLW} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.15}$$

$$\mathbf{STVFB} = \mathbf{STVFBO} + \mathbf{STVFBL} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{STVFBW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{STVFBLW} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.16}$$

$$\mathbf{ST2VFB} = \mathbf{ST2VFBO} \tag{3.17}$$

Process Parameters

$$\textbf{TOX} = \textbf{TOXO} \tag{3.18}$$

$$\textbf{EPSROX} = \textbf{EPSROXO} \tag{3.19}$$

$$N_{\text{sub0,eff}} = \textbf{NSUBO} \cdot \text{MAX}\left(\left[1 + \textbf{NSUBW} \cdot \frac{W_{\text{EN}}}{W_{\text{E}}} \cdot \ln\left(1 + \frac{W_{\text{E}}}{\textbf{WSEG}}\right)\right], 10^{-3}\right) \tag{3.20}$$

$$N_{\text{pck,eff}} = \textbf{NPCK} \cdot \text{MAX}\left(\left[1 + \textbf{NPCKW} \cdot \frac{W_{\text{EN}}}{W_{\text{E}}} \cdot \ln\left(1 + \frac{W_{\text{E}}}{\textbf{WSEGP}}\right)\right], 10^{-3}\right) \tag{3.21}$$

$$L_{\text{pck,eff}} = \textbf{LPCK} \cdot \text{MAX}\left(\left[1 + \textbf{LPCKW} \cdot \frac{W_{\text{EN}}}{W_{\text{E}}} \cdot \ln\left(1 + \frac{W_{\text{E}}}{\textbf{WSEGP}}\right)\right], 10^{-3}\right) \tag{3.22}$$

$$a = 7.5 \cdot 10^{10} \tag{3.23}$$

$$b = \sqrt{N_{\text{sub0,eff}} + 0.5 \cdot N_{\text{pck,eff}}} - \sqrt{N_{\text{sub0,eff}}} \tag{3.24}$$

$$N_{\text{sub}} = \begin{cases} N_{\text{sub0,eff}} + N_{\text{pck,eff}} \cdot \left[2 - \dfrac{L_{\text{E}}}{L_{\text{pck,eff}}}\right] & \text{for } L_{\text{E}} < L_{\text{pck,eff}} \\[2ex] N_{\text{sub0,eff}} + N_{\text{pck,eff}} \cdot \dfrac{L_{\text{pck,eff}}}{L_{\text{E}}} & \text{for } L_{\text{pck,eff}} \le L_{\text{E}} \le 2 \cdot L_{\text{pck,eff}} \\[2ex] \Bigg[\sqrt{N_{\text{sub0,eff}}} + & \\ \quad a \cdot \ln\left(1 + 2 \cdot \dfrac{L_{\text{pck,eff}}}{L_{\text{E}}} \cdot \left[\exp\left(\dfrac{b}{a}\right) - 1\right]\right)\Bigg]^2 & \text{for } L_{\text{E}} > 2 \cdot L_{\text{pck,eff}} \end{cases} \tag{3.25}$$

$$\textbf{NEFF} = N_{\text{sub}} \cdot \left(1 - \textbf{FOL1} \cdot \frac{L_{\text{EN}}}{L_{\text{E}}} - \textbf{FOL2} \cdot \left[\frac{L_{\text{EN}}}{L_{\text{E}}}\right]^2\right) \tag{3.26}$$

$$\begin{aligned} \textbf{GFACNUD} = \textbf{GFACNUDO} + \textbf{GFACNUDL} \cdot \left[\frac{L_{\text{EN}}}{L_{\text{E}}}\right]^{\textbf{GFACNUDLEXP}} \\ + \textbf{GFACNUDW} \cdot \frac{W_{\text{EN}}}{W_{\text{E}}} + \textbf{GFACNUDLW} \cdot \frac{A_{\text{EN}}}{A_{\text{E}}} \end{aligned} \tag{3.27}$$

$$\textbf{VSBNUD} = \textbf{VSBNUDO} \tag{3.28}$$

$$\textbf{DVSBNUD} = \textbf{DVSBNUDO} \tag{3.29}$$

$$\textbf{DPHIB} = \textbf{DPHIBO} + \textbf{DPHIBL} \cdot \left[\frac{L_{\text{EN}}}{L_{\text{E}}}\right]^{\textbf{DPHIBLEXP}} + \textbf{DPHIBW} \cdot \frac{W_{\text{EN}}}{W_{\text{E}}} + \textbf{DPHIBLW} \cdot \frac{A_{\text{EN}}}{A_{\text{E}}} \tag{3.30}$$

$$\textbf{NP} = \textbf{NPO} \cdot \text{MAX}\left(10^{-6}, 1 + \textbf{NPL} \cdot \frac{L_{\text{EN}}}{L_{\text{E}}}\right) \tag{3.31}$$

$$\textbf{TOXOV} = \textbf{TOXOVO} \tag{3.32}$$

$$\textbf{TOXOVD} = \textbf{TOXOVDO} \tag{3.33}$$

$$\textbf{NOV} = \textbf{NOVO} \tag{3.34}$$

$$\textbf{NOVD} = \textbf{NOVDO} \tag{3.35}$$

Interface States Parameters

$$\textbf{CT} = \left(\textbf{CTO} + \textbf{CTL} \cdot \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^{\textbf{CTLEXP}}\right) \cdot \left(1 + \textbf{CTW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \cdot \left(1 + \textbf{CTLW} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right) \tag{3.36}$$

$$\textbf{CTG} = \textbf{CTGO} \tag{3.37}$$

$$\textbf{CTB} = \textbf{CTBO} \tag{3.38}$$

$$\textbf{STCT} = \textbf{STCTO} \tag{3.39}$$

DIBL Parameters

$$\textbf{CF} = \textbf{CFL} \cdot \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^{\textbf{CFLEXP}} \cdot \left(1 + \textbf{CFW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \tag{3.40}$$

$$\textbf{CFB} = \textbf{CFBO} \tag{3.41}$$

$$\textbf{CFD} = \textbf{CFDO} \tag{3.42}$$

Subthreshold Slope Parameters

$$\textbf{PSCE} = \textbf{PSCEL} \cdot \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^{\textbf{PSCELEXP}} \cdot \left(1 + \textbf{PSCEW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \tag{3.43}$$

$$\textbf{PSCEB} = \textbf{PSCEBO} \tag{3.44}$$

$$\textbf{PSCED} = \textbf{PSCEDO} \tag{3.45}$$

Mobility Parameters

$$F_{\beta 1,\mathrm{eff}} = \textbf{FBET1} \cdot \left(1 + \textbf{FBET1W} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \tag{3.46}$$

$$L_{\mathrm{P1,eff}} = \textbf{LP1} \cdot \mathrm{MAX}\left(\left[1 + \textbf{LP1W} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right], 10^{-3}\right) \tag{3.47}$$

$$\begin{aligned} G_{\mathrm{P,E}} = 1 + F_{\beta 1,\mathrm{eff}} \cdot \frac{L_{\mathrm{P1,eff}}}{L_{\mathrm{E}}} \cdot \left[1 - \exp\left(-\frac{L_{\mathrm{E}}}{L_{\mathrm{P1,eff}}}\right)\right] + \\ \textbf{FBET2} \cdot \frac{\textbf{LP2}}{L_{\mathrm{E}}} \cdot \left[1 - \exp\left(-\frac{L_{\mathrm{E}}}{\textbf{LP2}}\right)\right] \end{aligned} \tag{3.48}$$

$$G_{\mathrm{W,E}} = 1 + \mathbf{BETW1} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{BETW2} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} \cdot \ln\left(1 + \frac{W_{\mathrm{E}}}{\mathbf{WBET}}\right) \tag{3.49}$$

$$\mathbf{BETN} = \frac{\mathbf{UO}}{G_{\mathrm{P,E}}} \cdot \frac{W_{\mathrm{E}}}{L_{\mathrm{E}}} \cdot G_{\mathrm{W,E}} \tag{3.50}$$

$$\mathbf{STBET} = \mathbf{STBETO} + \mathbf{STBETL} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{STBETW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{STBETLW} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.51}$$

$$\mathbf{MUE} = \mathbf{MUEO} \cdot \left[1 + \mathbf{MUEW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right] \tag{3.52}$$

$$\mathbf{STMUE} = \mathbf{STMUEO} \tag{3.53}$$

$$\mathbf{THEMU} = \mathbf{THEMUO} \tag{3.54}$$

$$\mathbf{STTHEMU} = \mathbf{STTHEMUO} \tag{3.55}$$

$$\mathbf{CS} = \left(\mathbf{CSO} + \mathbf{CSL} \cdot \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^{\mathbf{CSLEXP}}\right) \cdot \left(1 + \mathbf{CSW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \cdot \left(1 + \mathbf{CSLW} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right) \tag{3.56}$$

$$\mathbf{STCS} = \mathbf{STCSO} \tag{3.57}$$

$$\mathbf{THECS} = \mathbf{THECSO} \tag{3.58}$$

$$\mathbf{STTHECS} = \mathbf{STTHECSO} \tag{3.59}$$

$$\mathbf{XCOR} = \mathbf{XCORO} \cdot \left(1 + \mathbf{XCORL} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right) \cdot \left(1 + \mathbf{XCORW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \cdot \left(1 + \mathbf{XCORLW} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right) \tag{3.60}$$

$$\mathbf{STXCOR} = \mathbf{STXCORO} \tag{3.61}$$

$$\mathbf{FETA} = \mathbf{FETAO} \tag{3.62}$$

Series Resistance Parameters

$$\mathbf{RS} = \mathbf{RSW1} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} \cdot \left[1 + \mathbf{RSW2} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right] \tag{3.63}$$

$$\mathbf{STRS} = \mathbf{STRSO} \tag{3.64}$$

$$\mathbf{RSB} = \mathbf{RSBO} \tag{3.65}$$

$$\mathbf{RSG} = \mathbf{RSGO} \tag{3.66}$$

Velocity Saturation Parameters

$$\mathbf{THESAT} = \left(\mathbf{THESATO} + \mathbf{THESATL} \cdot \frac{G_{\mathrm{W,E}}}{G_{\mathrm{P,E}}} \cdot \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^{\mathbf{THESATLEXP}}\right) \cdot \left(1 + \mathbf{THESATW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \cdot \left(1 + \mathbf{THESATLW} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right) \tag{3.67}$$

$$\mathbf{STTHESAT} = \mathbf{STTHESATO} + \mathbf{STTHESATL} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{STTHESATW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{STTHESATLW} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.68}$$

$$\mathbf{THESATB} = \mathbf{THESATBO} \tag{3.69}$$

$$\mathbf{THESATG} = \mathbf{THESATGO} \tag{3.70}$$

$$\mathbf{THESATT} = \mathbf{THESATTO} \tag{3.71}$$

Linear to Saturation Transition Parameter

$$\mathbf{AX} = \frac{\mathbf{AXO}}{1 + \mathbf{AXL} \cdot \dfrac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}} \tag{3.72}$$

Channel Length Modulation (CLM) Parameters

$$\mathbf{ALP} = \mathbf{ALPL} \cdot \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^{\mathbf{ALPLEXP}} \cdot \left(1 + \mathbf{ALPW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \tag{3.73}$$

$$\mathbf{ALP1} = \frac{\mathbf{ALP1L1} \cdot \left[\dfrac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^{\mathbf{ALP1LEXP}}}{1 + \mathbf{ALP1L2} \cdot \left[\dfrac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^{\mathbf{ALP1LEXP}+1}} \cdot \left(1 + \mathbf{ALP1W} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \tag{3.74}$$

$$\mathbf{ALP2} = \frac{\mathbf{ALP2L1} \cdot \left[\dfrac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^{\mathbf{ALP2LEXP}}}{1 + \mathbf{ALP2L2} \cdot \left[\dfrac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^{\mathbf{ALP2LEXP}+1}} \cdot \left(1 + \mathbf{ALP2W} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \tag{3.75}$$

$$\mathbf{VP} = \mathbf{VPO} \tag{3.76}$$

Impact Ionization (II) Parameters

$$\mathbf{A1} = \mathbf{A1O} \cdot \left(1 + \mathbf{A1L} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right) \cdot \left(1 + \mathbf{A1W} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \tag{3.77}$$

$$\mathbf{A2} = \mathbf{A2O} \tag{3.78}$$

$$\mathbf{STA2} = \mathbf{STA2O} \tag{3.79}$$

$$\mathbf{A3} = \mathbf{A3O} \cdot \left(1 + \mathbf{A3L} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right) \cdot \left(1 + \mathbf{A3W} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \tag{3.80}$$

$$\mathbf{A4} = \mathbf{A4O} \cdot \left(1 + \mathbf{A4L} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right) \cdot \left(1 + \mathbf{A4W} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \tag{3.81}$$

Gate Current Parameters

$$\mathbf{GCO} = \mathbf{GCOO} \tag{3.82}$$

$$\mathbf{IGINV} = \mathbf{IGINVLW} \cdot \frac{A_{\mathrm{E}}}{A_{\mathrm{EN}}} \tag{3.83}$$

$$\mathbf{IGOV} = \mathbf{IGOVW} \cdot \frac{W_{\mathrm{E}} \cdot \mathbf{LOV}}{A_{\mathrm{EN}}} \tag{3.84}$$

$$\mathbf{IGOVD} = \mathbf{IGOVDW} \cdot \frac{W_{\mathrm{E}} \cdot \mathbf{LOVD}}{A_{\mathrm{EN}}} \tag{3.85}$$

$$\mathbf{STIG} = \mathbf{STIGO} \tag{3.86}$$

$$\mathbf{GC2} = \mathbf{GC2O} \tag{3.87}$$

$$\mathbf{GC3} = \mathbf{GC3O} \tag{3.88}$$

$$\mathbf{GC2OV} = \mathbf{GC2OVO} \tag{3.89}$$

$$\mathbf{GC3OV} = \mathbf{GC3OVO} \tag{3.90}$$

$$\mathbf{CHIB} = \mathbf{CHIBO} \tag{3.91}$$

Gate-Induced Drain Leakage (GIDL) Parameters

$$\mathbf{AGIDL} = \mathbf{AGIDLW} \cdot \frac{W_{\mathrm{E}} \cdot \mathbf{LOV}}{A_{\mathrm{EN}}} \tag{3.92}$$

$$\mathbf{AGIDLD} = \mathbf{AGIDLDW} \cdot \frac{W_{\mathrm{E}} \cdot \mathbf{LOVD}}{A_{\mathrm{EN}}} \tag{3.93}$$

$$\mathbf{BGIDL} = \mathbf{BGIDLO} \tag{3.94}$$

$$\mathbf{BGIDLD} = \mathbf{BGIDLDO} \tag{3.95}$$

$$\mathbf{STBGIDL} = \mathbf{STBGIDLO} \tag{3.96}$$

$$\mathbf{STBGIDLD} = \mathbf{STBGIDLDO} \tag{3.97}$$

$$\mathbf{CGIDL} = \mathbf{CGIDLO} \tag{3.98}$$

$$\mathbf{CGIDLD} = \mathbf{CGIDLDO} \tag{3.99}$$

Charge Model Parameters

$$\epsilon_{\text{ox}} = \epsilon_0 \cdot \textbf{EPSROX} \tag{3.100}$$

$$\textbf{COX} = \epsilon_{\text{ox}} \cdot \frac{W_{\text{E,CV}} \cdot L_{\text{E,CV}}}{\textbf{TOX}} \tag{3.101}$$

$$\begin{aligned}\textbf{DELVTAC} = \textbf{DELVTACO} + \textbf{DELVTACL} \cdot \left[\frac{L_{\text{EN}}}{L_{\text{E}}}\right]^{\textbf{DELVTACLEXP}} \\ + \textbf{DELVTACW} \cdot \frac{W_{\text{EN}}}{W_{\text{E}}} + \textbf{DELVTACLW} \cdot \frac{A_{\text{EN}}}{A_{\text{E}}}\end{aligned} \tag{3.102}$$

$$\begin{aligned}\textbf{FACNEFFAC} = \textbf{FACNEFFACO} + \textbf{FACNEFFACL} \cdot \frac{L_{\text{EN}}}{L_{\text{E}}} \\ + \textbf{FACNEFFACW} \cdot \frac{W_{\text{EN}}}{W_{\text{E}}} + \textbf{FACNEFFACLW} \cdot \frac{A_{\text{EN}}}{A_{\text{E}}}\end{aligned} \tag{3.103}$$

$$\begin{aligned}\textbf{THESATAC} = \left(\textbf{THESATACO} + \textbf{THESATACL} \cdot \frac{G_{\text{W,E}}}{G_{\text{P,E}}} \cdot \left[\frac{L_{\text{EN}}}{L_{\text{E}}}\right]^{\textbf{THESATACLEXP}}\right) \\ \cdot \left(1 + \textbf{THESATACW} \cdot \frac{W_{\text{EN}}}{W_{\text{E}}}\right) \cdot \left(1 + \textbf{THESATACLW} \cdot \frac{A_{\text{EN}}}{A_{\text{E}}}\right)\end{aligned} \tag{3.104}$$

$$\textbf{AXAC} = \frac{\textbf{AXACO}}{1 + \textbf{AXACL} \cdot \dfrac{L_{\text{EN}}}{L_{\text{E}}}} \tag{3.105}$$

$$\textbf{ALPAC} = \textbf{ALPACL} \cdot \left[\frac{L_{\text{EN}}}{L_{\text{E}}}\right]^{\textbf{ALPACLEXP}} \cdot \left(1 + \textbf{ALPACW} \cdot \frac{W_{\text{EN}}}{W_{\text{E}}}\right) \tag{3.106}$$

$$\textbf{ALP1AC} = \frac{\textbf{ALP1ACL1} \cdot \left[\dfrac{L_{\text{EN}}}{L_{\text{E}}}\right]^{\textbf{ALP1ACLEXP}}}{1 + \textbf{ALP1ACL2} \cdot \left[\dfrac{L_{\text{EN}}}{L_{\text{E}}}\right]^{\textbf{ALP1ACLEXP}+1}} \cdot \left(1 + \textbf{ALP1ACW} \cdot \frac{W_{\text{EN}}}{W_{\text{E}}}\right) \tag{3.107}$$

$$\textbf{CGOV} = \epsilon_{\text{ox}} \cdot \frac{W_{\text{E,CV}} \cdot \textbf{LOV}}{\textbf{TOXOV}} \tag{3.108}$$

$$\textbf{CGOVD} = \epsilon_{\text{ox}} \cdot \frac{W_{\text{E,CV}} \cdot \textbf{LOVD}}{\textbf{TOXOVD}} \tag{3.109}$$

$$\textbf{FCGOVACC} = \textbf{FCGOVACCO} \tag{3.110}$$

$$\textbf{FCGOVACCD} = \textbf{FCGOVACCDO} \tag{3.111}$$

$$\textbf{CGOVACCG} = \textbf{CGOVACCGO} \tag{3.112}$$

$$\textbf{CGBOV} = \textbf{CGBOVL} \cdot \frac{L_{\text{G,CV}}}{L_{\text{EN}}} \tag{3.113}$$

$$\textbf{CINR} = \textbf{CINRW} \cdot \frac{W_{\rm E,CV}}{W_{\rm EN}} \tag{3.114}$$

$$\textbf{CINRD} = \textbf{CINRDW} \cdot \frac{W_{\rm E,CV}}{W_{\rm EN}} \tag{3.115}$$

$$\textbf{DVFBINR} = \textbf{DVFBINRO} \tag{3.116}$$

$$\textbf{FCINRDEP} = \textbf{FCINRDEPO} \tag{3.117}$$

$$\textbf{FCINRACC} = \textbf{FCINRACCO} \tag{3.118}$$

$$\textbf{AXINR} = \textbf{AXINRO} \tag{3.119}$$

$$\textbf{CFR} = \textbf{CFRW} \cdot \frac{W_{\rm G,CV}}{W_{\rm EN}} \tag{3.120}$$

$$\textbf{CFRD} = \textbf{CFRDW} \cdot \frac{W_{\rm G,CV}}{W_{\rm EN}} \tag{3.121}$$

Noise Model Parameters

Note that the equation below makes use of the value of **BETN** calculated in Eq. (3.50). Because **BETN** is roughly proportional to $W_{\rm E}/L_{\rm E}$, the resulting **FNTEXC** is roughly proportional to $1/L_{\rm E}^2$. In addition, it will inherit some minor L- and W-dependence from **BETN**.

$$\textbf{FNTEXC} = \textbf{FNTEXCL} \cdot \textbf{BETN}^2 \cdot \left[\frac{W_{\rm EN}}{W_{\rm E}}\right]^2 \tag{3.122}$$

$$L_{\rm noi} = \mathrm{MAX}\left(1 - \frac{2 \cdot \textbf{LINTNOI}}{L_{\rm E}}, 10^{-3}\right) \tag{3.123}$$

$$L_{\rm red} = \frac{1}{L_{\rm noi}^{\textbf{ALPNOI}}} \tag{3.124}$$

$$\textbf{NFA} = L_{\rm red} \cdot \textbf{NFALW} \cdot \frac{A_{\rm EN}}{A_{\rm E}} \tag{3.125}$$

$$\textbf{NFB} = L_{\rm red} \cdot \textbf{NFBLW} \cdot \frac{A_{\rm EN}}{A_{\rm E}} \tag{3.126}$$

$$\textbf{NFC} = L_{\rm red} \cdot \textbf{NFCLW} \cdot \frac{A_{\rm EN}}{A_{\rm E}} \tag{3.127}$$

$$\textbf{EF} = \textbf{EFO} \tag{3.128}$$

Edge Transistor Parameters

$$W_{\rm E,edge} = 2 \cdot \textbf{WEDGE} + \textbf{WEDGEW} \cdot W_{\rm E} \tag{3.129}$$

$$\textbf{VFBEDGE} = \textbf{VFBEDGEO} \tag{3.130}$$

$$\begin{aligned}\mathbf{STVFBEDGE} = \mathbf{STVFBEDGEO} + \mathbf{STVFBEDGEL} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} \\ + \mathbf{STVFBEDGEW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{STVFBEDGELW} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\end{aligned} \tag{3.131}$$

$$\begin{aligned}\mathbf{DPHIBEDGE} = \mathbf{DPHIBEDGEO} + \mathbf{DPHIBEDGEL} \cdot \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^{\mathbf{DPHIBEDGELEXP}} \\ + \mathbf{DPHIBEDGEW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{DPHIBEDGELW} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\end{aligned} \tag{3.132}$$

$$\begin{aligned}\mathbf{NEFFEDGE} = \mathbf{NSUBEDGEO} \cdot \left(1 + \mathbf{NSUBEDGEL} \cdot \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^{\mathbf{NSUBEDGELEXP}}\right) \\ \cdot \left(1 + \mathbf{NSUBEDGEW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \cdot \left(1 + \mathbf{NSUBEDGELW} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right)\end{aligned} \tag{3.133}$$

$$\mathbf{CTEDGE} = \mathbf{CTEDGEO} + \mathbf{CTEDGEL} \cdot \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^{\mathbf{CTEDGELEXP}} \tag{3.134}$$

$$G_{\mathrm{PE,edge}} = 1 + \mathbf{FBETEDGE} \cdot \frac{\mathbf{LPEDGE}}{L_{\mathrm{E}}} \cdot \left[1 - \exp\left(-\frac{L_{\mathrm{E}}}{\mathbf{LPEDGE}}\right)\right] \tag{3.135}$$

$$\mathbf{BETNEDGE} = \frac{\mathbf{UO}}{G_{\mathrm{PE,edge}}} \cdot \frac{W_{\mathrm{E,edge}}}{L_{\mathrm{E}}} \cdot \left(1 + \mathbf{BETEDGEW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \tag{3.136}$$

$$\begin{aligned}\mathbf{STBETEDGE} = \mathbf{STBETEDGEO} + \mathbf{STBETEDGEL} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} \\ + \mathbf{STBETEDGEW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{STBETEDGELW} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\end{aligned} \tag{3.137}$$

$$\mathbf{PSCEEDGE} = \mathbf{PSCEEDGEL} \cdot \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^{\mathbf{PSCEEDGELEXP}} \cdot \left(1 + \mathbf{PSCEEDGEW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \tag{3.138}$$

$$\mathbf{PSCEBEDGE} = \mathbf{PSCEBEDGEO} \tag{3.139}$$

$$\mathbf{PSCEDEDGE} = \mathbf{PSCEDEDGEO} \tag{3.140}$$

$$\mathbf{CFEDGE} = \mathbf{CFEDGEL} \cdot \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^{\mathbf{CFEDGELEXP}} \cdot \left(1 + \mathbf{CFEDGEW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \tag{3.141}$$

$$\mathbf{CFDEDGE} = \mathbf{CFDEDGEO} \tag{3.142}$$

$$\mathbf{CFBEDGE} = \mathbf{CFBEDGEO} \tag{3.143}$$

$$\mathbf{FNTEDGE} = \mathbf{FNTEDGEO} \tag{3.144}$$

$$\mathbf{NFAEDGE} = \mathbf{NFAEDGELW} \cdot \frac{A_{\mathrm{EN}}}{W_{\mathrm{E,edge}} \cdot L_{\mathrm{E}}} \tag{3.145}$$

$$\mathbf{NFBEDGE} = \mathbf{NFBEDGELW} \cdot \frac{A_{\mathrm{EN}}}{W_{\mathrm{E,edge}} \cdot L_{\mathrm{E}}} \tag{3.146}$$

$$\mathbf{NFCEDGE} = \mathbf{NFCEDGELW} \cdot \frac{A_{\mathrm{EN}}}{W_{\mathrm{E,edge}} \cdot L_{\mathrm{E}}} \tag{3.147}$$

$$\mathbf{EFEDGE} = \mathbf{EFEDGEO} \tag{3.148}$$

Self heating parameters

$$\mathbf{RTH} = \mathbf{RTHO} + \frac{\mathbf{RTHW1}}{\mathbf{RTHW2} + \frac{W_{\mathrm{E}}}{W_{\mathrm{EN}}} \cdot \left[1 + \mathbf{RTHLW} \cdot \frac{L_{\mathrm{E}}}{L_{\mathrm{EN}}}\right]} \tag{3.149}$$

$$\mathbf{CTH} = \mathbf{CTHO} + \mathbf{CTHW1} \cdot \left[\mathbf{CTHW2} + \frac{W_{\mathrm{E}}}{W_{\mathrm{EN}}} \cdot \left(1 + \mathbf{CTHLW} \cdot \frac{L_{\mathrm{E}}}{L_{\mathrm{EN}}}\right)\right] \tag{3.150}$$

$$\mathbf{STRTH} = \mathbf{STRTHO} \tag{3.151}$$

NQS parameters

$$\mathbf{MUNQS} = \mathbf{MUNQSO} \tag{3.152}$$

3.4 Binning Rules Equations

The binning equations are provided as a (phenomenological) alternative to the physical scaling equations for computing local parameters. The physical geometrical scaling rules have been developed to give a good description over the whole geometry range of CMOS technologies. For processes under development, however, it is sometimes useful to have more flexible scaling relations. In that case, a binning strategy could be opt where the accuracy with geometry is mostly determined by the number of bins used. The classical binning scaling rule is based on first order developments of the geometrical scaling rules in terms of $1/L_\mathrm{E}$, $1/W_\mathrm{E}$, and $1/A_\mathrm{E}$. As example below, the case of a fictitious parameter **YYY**):

$$\mathbf{YYY} = \mathbf{POYYY} + \mathbf{PLYYY} \cdot \frac{L_\mathrm{EN}}{L_\mathrm{E}} + \mathbf{PWYYY} \cdot \frac{W_\mathrm{EN}}{W_\mathrm{E}} + \mathbf{PLWYYY} \cdot \frac{A_\mathrm{EN}}{A_\mathrm{E}} \tag{3.153}$$

However, to conserve the first order of the scaling rules, a factor can be added from this equation. In the case of the fictitious parameter **YYY**:

$$\mathbf{YYY} = F_{YYY} \cdot \left[\mathbf{POYYY} + \mathbf{PLYYY} \cdot \frac{L_\mathrm{EN}}{L_\mathrm{E}} + \mathbf{PWYYY} \cdot \frac{W_\mathrm{EN}}{W_\mathrm{E}} + \mathbf{PLWYYY} \cdot \frac{A_\mathrm{EN}}{A_\mathrm{E}}\right] \tag{3.154}$$

This factor F_{YYY} is the basic scaling rule. As example, the factor of the intrinsic oxide capacitance **COX** is:

$$F_{COX} = \frac{L_\mathrm{E,CV} \cdot W_\mathrm{E,CV}}{A_\mathrm{EN}} \tag{3.155}$$

In Table 3.2, a survey of the binning type used foreach local parameter is given. In some cases where the geometrical scaling rule is constant, the binning rule is chosen to be more flexible.

Note: for each local parameter, the binning scaling rule is activated when at least one of the binning parameters is assigned.

When using the binning rules above, the binning parameters for one bin can be directly calculated from the local parameter sets of the four corner devices of the bin (see Sec. **??**). This results in a *separate parameter set for each bin*. The binning scheme ensures that the local parameters are exactly reproduced at the bin corners and that no humps occur in the local parameter values across bin boundaries.

Note: After calculation of the local parameters from the binning rules (and possible applications of the stress equations in Section 3.6 and well proximity equations in Section 3.7), clipping is applied according to Section 2.5.2.

Table 3.1: Overview of local parameters and binning type. The third column indicates whether there is a physical geometrical scaling rule for the local parameters.

#	parameter	physical scaling	binning	#	parameter	physical scaling	binning
1	**DTA**	no	no	44	**THESAT**	yes	yes
2	**VFB**	yes	yes	45	**STTHESAT**	yes	yes
3	**STVFB**	yes	yes	46	**THESATB**	no	yes
4	**ST2VFB**	no	no	47	**THESATG**	no	yes
5	**TOX**	no	no	48	**THESATT**	no	no
6	**EPSRO**	no	no	49	**AX**	yes	yes
7	**NEFF**	yes	yes	50	**ALP**	yes	yes
8	**GFACNUD**	yes	yes	51	**ALP1**	yes	yes
9	**VSBNUD**	no	yes	52	**ALP2**	yes	yes
10	**DVSBNUD**	no	no	53	**VP**	no	no
11	**DPHIB**	yes	yes	54	**A1**	yes	yes
12	**NP**	yes	yes	55	**A2**	no	no
13	**TOXOV**	no	no	56	**STA2**	no	yes
14	**TOXOVD**	no	no	57	**A3**	yes	yes
15	**NOV**	no	yes	58	**A4**	yes	yes
16	**NOVD**	no	yes	59	**GCO**	no	no
17	**CT**	yes	yes	60	**IGINV**	yes	yes
18	**CTG**	no	yes	61	**IGOV**	yes	yes
19	**CTB**	no	yes	62	**IGOVD**	yes	yes
20	**STCT**	no	yes	63	**STIG**	no	yes
21	**CF**	yes	yes	64	**GC2**	no	no
22	**CFD**	no	yes	65	**GC3**	no	no
23	**CFB**	no	yes	66	**GC2OV**	no	no
24	**PSCE**	yes	yes	67	**GC3OV**	no	no
25	**PSCEB**	no	yes	68	**CHIB**	no	no
26	**PSCED**	no	yes	69	**AGIDL**	yes	yes
27	**BETN**	yes	yes	70	**AGIDLD**	yes	yes
28	**STBET**	yes	yes	71	**BGIDL**	no	no
29	**MUE**	yes	yes	72	**BGIDLD**	no	no
30	**STMUE**	no	no	73	**STBGIDL**	no	yes
31	**THEMU**	no	yes	74	**STBGIDLD**	no	yes
32	**STTHEMU**	no	no	75	**CGIDL**	no	no
33	**CS**	yes	yes	76	**CGIDLD**	no	no
34	**STCS**	no	no	77	**COX**	yes	yes
35	**THECS**	no	yes	78	**DELVTAC**	yes	yes
36	**STTHECS**	no	no	79	**FACNEFFAC**	yes	yes
37	**XCOR**	yes	yes	80	**THESATAC**	yes	yes
38	**STXCOR**	no	no	81	**AXAC**	yes	yes
39	**FETA**	no	no	82	**ALPAC**	yes	yes
40	**RS**	yes	yes	83	**ALP1AC**	yes	yes
41	**STRS**	no	yes	84	**CGOV**	yes	yes
42	**RSB**	no	yes	85	**CGOVD**	yes	yes
43	**RSG**	no	yes	86	**FCGOVACC**	no	no

Table 3.2: Overview of local parameters and binning type. The third column indicates whether there is a physical geometrical scaling rule for the local parameters.

#	parameter	physical scaling	binning	#	parameter	physical scaling	binning
87	**FCGOVACCD**	no	no	107	**NEFFEDGE**	yes	yes
88	**CGOVACCG**	no	no	108	**CTEDGE**	yes	yes
89	**CGBOV**	yes	yes	109	**BETNEDGE**	yes	yes
90	**CINR**	yes	yes	110	**STBETEDGE**	yes	yes
91	**CINRD**	yes	yes	111	**PSCEEDGE**	yes	yes
92	**DVFBINR**	no	no	112	**PSCEBEDGE**	no	yes
93	**FCINRDEP**	no	no	113	**PSCEDEDGE**	no	yes
94	**FCINRACC**	no	no	114	**CFEDGE**	yes	yes
95	**AXINR**	no	no	115	**CFDEDGE**	no	yes
96	**CFR**	yes	yes	116	**CFBEDGE**	no	yes
97	**CFRD**	yes	yes	117	**FNTEDGE**	no	no
98	**FNT**	no	no	118	**NFAEDGE**	yes	yes
99	**FNTEXC**	yes	yes	119	**NFBEDGE**	yes	yes
100	**NFA**	yes	yes	120	**NFCEDGE**	yes	yes
101	**NFB**	yes	yes	121	**EFEDGE**	no	no
102	**NFC**	yes	yes	122	**RTH**	yes	yes
103	**EF**	no	no	123	**CTH**	yes	yes
104	**VFBEDGE**	no	yes	124	**STRTH**	no	yes
105	**STVFBEDGE**	yes	yes	125	**MUNQS**	no	yes
106	**DPHIBEDGE**	yes	yes				

Flat-Band Voltage Parameters

$$\mathbf{VFB} = \mathbf{POVFB} + \mathbf{PLVFB} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWVFB} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWVFB} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.156}$$

$$\mathbf{STVFB} = \mathbf{POSTVFB} + \mathbf{PLSTVFB} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWSTVFB} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWSTVFB} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.157}$$

Process Parameters

$$\mathbf{NEFF} = \mathbf{PONEFF} + \mathbf{PLNEFF} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWNEFF} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWNEFF} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.158}$$

$$\begin{aligned}\mathbf{GFACNUD} = \mathbf{POGFACNUD} + \mathbf{PLGFACNUD} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \\ \mathbf{PWGFACNUD} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWGFACNUD} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\end{aligned} \tag{3.159}$$

$$\begin{aligned}\mathbf{VSBNUD} = \mathbf{POVSBNUD} + \mathbf{PLVSBNUD} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \\ \mathbf{PWVSBNUD} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWVSBNUD} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\end{aligned} \tag{3.160}$$

$$\mathbf{DPHIB} = \mathbf{PODPHIB} + \mathbf{PLDPHIB} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWDPHIB} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWDPHIB} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.161}$$

$$\mathbf{NP} = \mathbf{PONP} + \mathbf{PLNP} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWNP} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWNP} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.162}$$

$$\mathbf{NOV} = \mathbf{PONOV} + \mathbf{PLNOV} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWNOV} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWNOV} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.163}$$

$$\mathbf{NOVD} = \mathbf{PONOVD} + \mathbf{PLNOVD} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWNOVD} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWNOVD} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.164}$$

Interface States Parameters

$$\mathbf{CT} = \mathbf{POCT} + \mathbf{PLCT} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWCT} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWCT} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.165}$$

$$\mathbf{CTG} = \mathbf{POCTG} + \mathbf{PLCTG} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWCTG} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWCTG} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.166}$$

$$\mathbf{CTB} = \mathbf{POCTB} + \mathbf{PLCTB} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWCTB} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWCTB} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.167}$$

$$\mathbf{STCT} = \mathbf{POSTCT} + \mathbf{PLSTCT} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWSTCT} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWSTCT} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.168}$$

DIBL Parameters

$$\mathbf{CF} = \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^2 \cdot \left[\mathbf{POCF} + \mathbf{PLCF} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWCF} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWCF} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right] \tag{3.169}$$

$$\mathbf{CFB} = \mathbf{POCFB} + \mathbf{PLCFB} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWCFB} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWCFB} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.170}$$

$$\mathbf{CFD} = \mathbf{POCFD} + \mathbf{PLCFD} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWCFD} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWCFD} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.171}$$

Subthreshold Slope Parameters

$$\begin{aligned}\mathbf{PSCE} = \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^2 \cdot \Bigg[&\mathbf{POPSCE} + \mathbf{PLPSCE} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \\ &\mathbf{PWPSCE} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWPSCE} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\Bigg]\end{aligned} \tag{3.172}$$

$$\mathbf{PSCEB} = \mathbf{POPSCEB} + \mathbf{PLPSCEB} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWPSCEB} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWPSCEB} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.173}$$

$$\mathbf{PSCED} = \mathbf{POPSCED} + \mathbf{PLPSCED} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWPSCED} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWPSCED} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.174}$$

Mobility Parameters

$$\mathbf{BETN} = \frac{W_\mathrm{E}}{L_\mathrm{E}} \cdot \left[\mathbf{POBETN} + \mathbf{PLBETN} \cdot \frac{L_\mathrm{EN}}{L_\mathrm{E}} + \mathbf{PWBETN} \cdot \frac{W_\mathrm{EN}}{W_\mathrm{E}} + \mathbf{PLWBETN} \cdot \frac{A_\mathrm{EN}}{A_\mathrm{E}}\right] \tag{3.175}$$

$$\mathbf{STBET} = \mathbf{POSTBET} + \mathbf{PLSTBET} \cdot \frac{L_\mathrm{EN}}{L_\mathrm{E}} + \mathbf{PWSTBET} \cdot \frac{W_\mathrm{EN}}{W_\mathrm{E}} + \mathbf{PLWSTBET} \cdot \frac{A_\mathrm{EN}}{A_\mathrm{E}} \tag{3.176}$$

$$\mathbf{MUE} = \mathbf{POMUE} + \mathbf{PLMUE} \cdot \frac{L_\mathrm{EN}}{L_\mathrm{E}} + \mathbf{PWMUE} \cdot \frac{W_\mathrm{EN}}{W_\mathrm{E}} + \mathbf{PLWMUE} \cdot \frac{A_\mathrm{EN}}{A_\mathrm{E}} \tag{3.177}$$

$$\begin{aligned}\mathbf{THEMU} = \mathbf{POTHEMU} + \mathbf{PLTHEMU} \cdot \frac{L_\mathrm{EN}}{L_\mathrm{E}} + \\ \mathbf{PWTHEMU} \cdot \frac{W_\mathrm{EN}}{W_\mathrm{E}} + \mathbf{PLWTHEMU} \cdot \frac{A_\mathrm{EN}}{A_\mathrm{E}}\end{aligned} \tag{3.178}$$

$$\mathbf{CS} = \mathbf{POCS} + \mathbf{PLCS} \cdot \frac{L_\mathrm{EN}}{L_\mathrm{E}} + \mathbf{PWCS} \cdot \frac{W_\mathrm{EN}}{W_\mathrm{E}} + \mathbf{PLWCS} \cdot \frac{A_\mathrm{EN}}{A_\mathrm{E}} \tag{3.179}$$

$$\mathbf{THECS} = \mathbf{POTHECS} + \mathbf{PLTHECS} \cdot \frac{L_\mathrm{EN}}{L_\mathrm{E}} + \mathbf{PWTHECS} \cdot \frac{W_\mathrm{EN}}{W_\mathrm{E}} + \mathbf{PLWTHECS} \cdot \frac{A_\mathrm{EN}}{A_\mathrm{E}} \tag{3.180}$$

$$\mathbf{XCOR} = \mathbf{POXCOR} + \mathbf{PLXCOR} \cdot \frac{L_\mathrm{EN}}{L_\mathrm{E}} + \mathbf{PWXCOR} \cdot \frac{W_\mathrm{EN}}{W_\mathrm{E}} + \mathbf{PLWXCOR} \cdot \frac{A_\mathrm{EN}}{A_\mathrm{E}} \tag{3.181}$$

Series Resistance Parameters

$$\mathbf{RS} = \frac{W_\mathrm{EN}}{W_\mathrm{E}} \cdot \left[\mathbf{PORS} + \mathbf{PLRS} \cdot \frac{L_\mathrm{EN}}{L_\mathrm{E}} + \mathbf{PWRS} \cdot \frac{W_\mathrm{EN}}{W_\mathrm{E}} + \mathbf{PLWRS} \cdot \frac{A_\mathrm{EN}}{A_\mathrm{E}}\right] \tag{3.182}$$

$$\mathbf{STRS} = \mathbf{POSTRS} + \mathbf{PLSTRS} \cdot \frac{L_\mathrm{EN}}{L_\mathrm{E}} + \mathbf{PWSTRS} \cdot \frac{W_\mathrm{EN}}{W_\mathrm{E}} + \mathbf{PLWSTRS} \cdot \frac{A_\mathrm{EN}}{A_\mathrm{E}} \tag{3.183}$$

$$\mathbf{RSB} = \mathbf{PORSB} + \mathbf{PLRSB} \cdot \frac{L_\mathrm{EN}}{L_\mathrm{E}} + \mathbf{PWRSB} \cdot \frac{W_\mathrm{EN}}{W_\mathrm{E}} + \mathbf{PLWRSB} \cdot \frac{A_\mathrm{EN}}{A_\mathrm{E}} \tag{3.184}$$

$$\mathbf{RSG} = \mathbf{PORSG} + \mathbf{PLRSG} \cdot \frac{L_\mathrm{EN}}{L_\mathrm{E}} + \mathbf{PWRSG} \cdot \frac{W_\mathrm{EN}}{W_\mathrm{E}} + \mathbf{PLWRSG} \cdot \frac{A_\mathrm{EN}}{A_\mathrm{E}} \tag{3.185}$$

Velocity Saturation Parameters

$$\begin{aligned}\mathbf{THESAT} = \frac{L_\mathrm{EN}}{L_\mathrm{E}} \cdot \Bigg[\mathbf{POTHESAT} + \mathbf{PLTHESAT} \cdot \frac{L_\mathrm{EN}}{L_\mathrm{E}} + \\ \mathbf{PWTHESAT} \cdot \frac{W_\mathrm{EN}}{W_\mathrm{E}} + \mathbf{PLWTHESAT} \cdot \frac{A_\mathrm{EN}}{A_\mathrm{E}}\Bigg]\end{aligned} \tag{3.186}$$

$$\begin{aligned}\mathbf{STTHESAT} = \mathbf{POSTTHESAT} + \mathbf{PLSTTHESAT} \cdot \frac{L_\mathrm{EN}}{L_\mathrm{E}} + \\ \mathbf{PWSTTHESAT} \cdot \frac{W_\mathrm{EN}}{W_\mathrm{E}} + \mathbf{PLWSTTHESAT} \cdot \frac{A_\mathrm{EN}}{A_\mathrm{E}}\end{aligned} \tag{3.187}$$

$$\mathbf{THESATB} = \mathbf{POTHESATB} + \mathbf{PLTHESATB} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWTHESATB} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWTHESATB} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.188}$$

$$\mathbf{THESATG} = \mathbf{POTHESATG} + \mathbf{PLTHESATG} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWTHESATG} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWTHESATG} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.189}$$

Linear to Saturation Transition Parameters

$$\mathbf{AX} = \mathbf{POAX} + \mathbf{PLAX} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWAX} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWAX} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.190}$$

Channel Length Modulation (CLM) Parameters

$$\mathbf{ALP} = \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} \cdot \left[\mathbf{POALP} + \mathbf{PLALP} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWALP} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWALP} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right] \tag{3.191}$$

$$\mathbf{ALP1} = \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} \cdot \left[\mathbf{POALP1} + \mathbf{PLALP1} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWALP1} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWALP1} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right] \tag{3.192}$$

$$\mathbf{ALP2} = \mathbf{POALP2} + \mathbf{PLALP2} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWALP2} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWALP2} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.193}$$

Impact Ionization (II) Parameters

$$\mathbf{A1} = \mathbf{POA1} + \mathbf{PLA1} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWA1} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWA1} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.194}$$

$$\mathbf{STA2} = \mathbf{POSTA2} + \mathbf{PLSTA2} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWSTA2} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWSTA2} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.195}$$

$$\mathbf{A3} = \mathbf{POA3} + \mathbf{PLA3} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWA3} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWA3} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.196}$$

$$\mathbf{A4} = \mathbf{POA4} + \mathbf{PLA4} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWA4} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWA4} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.197}$$

Gate Current Parameters

$$\mathbf{IGINV} = \frac{A_{\mathrm{E}}}{A_{\mathrm{EN}}} \cdot \left[\mathbf{POIGINV} + \mathbf{PLIGINV} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWIGINV} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWIGINV} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right] \tag{3.198}$$

$$\mathbf{IGOV} = \frac{W_{\mathrm{E}}}{W_{\mathrm{EN}}} \cdot \left[\mathbf{POIGOV} + \mathbf{PLIGOV} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWIGOV} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWIGOV} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right] \tag{3.199}$$

$$\textbf{IGOVD} = \frac{W_{\rm E}}{W_{\rm EN}} \cdot \Bigg[\textbf{POIGOVD} + \textbf{PLIGOVD} \cdot \frac{L_{\rm EN}}{L_{\rm E}} + \textbf{PWIGOVD} \cdot \frac{W_{\rm EN}}{W_{\rm E}} + \textbf{PLWIGOVD} \cdot \frac{A_{\rm EN}}{A_{\rm E}}\Bigg] \tag{3.200}$$

$$\textbf{STIG} = \textbf{POSTIG} + \textbf{PLSTIG} \cdot \frac{L_{\rm EN}}{L_{\rm E}} + \textbf{PWSTIG} \cdot \frac{W_{\rm EN}}{W_{\rm E}} + \textbf{PLWSTIG} \cdot \frac{A_{\rm EN}}{A_{\rm E}} \tag{3.201}$$

Gate-Induced Drain Leakage (GIDL) Parameters

$$\textbf{AGIDL} = \frac{W_{\rm E}}{W_{\rm EN}} \cdot \Bigg[\textbf{POAGIDL} + \textbf{PLAGIDL} \cdot \frac{L_{\rm EN}}{L_{\rm E}} + \textbf{PWAGIDL} \cdot \frac{W_{\rm EN}}{W_{\rm E}} + \textbf{PLWAGIDL} \cdot \frac{A_{\rm EN}}{A_{\rm E}}\Bigg] \tag{3.202}$$

$$\textbf{AGIDLD} = \frac{W_{\rm E}}{W_{\rm EN}} \cdot \Bigg[\textbf{POAGIDLD} + \textbf{PLAGIDLD} \cdot \frac{L_{\rm EN}}{L_{\rm E}} + \textbf{PWAGIDLD} \cdot \frac{W_{\rm EN}}{W_{\rm E}} + \textbf{PLWAGIDLD} \cdot \frac{A_{\rm EN}}{A_{\rm E}}\Bigg] \tag{3.203}$$

$$\textbf{STBGIDL} = \textbf{POSTBGIDL} + \textbf{PLSTBGIDL} \cdot \frac{L_{\rm EN}}{L_{\rm E}} + \textbf{PWSTBGIDL} \cdot \frac{W_{\rm EN}}{W_{\rm E}} + \textbf{PLWSTBGIDL} \cdot \frac{A_{\rm EN}}{A_{\rm E}} \tag{3.204}$$

$$\textbf{STBGIDLD} = \textbf{POSTBGIDLD} + \textbf{PLSTBGIDLD} \cdot \frac{L_{\rm EN}}{L_{\rm E}} + \textbf{PWSTBGIDLD} \cdot \frac{W_{\rm EN}}{W_{\rm E}} + \textbf{PLWSTBGIDLD} \cdot \frac{A_{\rm EN}}{A_{\rm E}} \tag{3.205}$$

Charge Model Parameters

$$\textbf{COX} = \frac{L_{\rm E,CV} \cdot W_{\rm E,CV}}{A_{\rm EN}} \cdot \Bigg[\textbf{POCOX} + \textbf{PLCOX} \cdot \frac{L_{\rm EN}}{L_{\rm E}} + \textbf{PWCOX} \cdot \frac{W_{\rm EN}}{W_{\rm E}} + \textbf{PLWCOX} \cdot \frac{A_{\rm EN}}{A_{\rm E}}\Bigg] \tag{3.206}$$

$$\textbf{DELVTAC} = \textbf{PODELVTAC} + \textbf{PLDELVTAC} \cdot \frac{L_{\rm EN}}{L_{\rm E}} + \textbf{PWDELVTAC} \cdot \frac{W_{\rm EN}}{W_{\rm E}} + \textbf{PLWDELVTAC} \cdot \frac{A_{\rm EN}}{A_{\rm E}} \tag{3.207}$$

$$\mathbf{FACNEFFAC} = \mathbf{POFACNEFFAC} + \mathbf{PLFACNEFFAC} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWFACNEFFAC} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWFACNEFFAC} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.208}$$

$$\mathbf{THESATAC} = \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} \cdot \left[\mathbf{POTHESATAC} + \mathbf{PLTHESATAC} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWTHESATAC} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWTHESATAC} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right] \tag{3.209}$$

$$\mathbf{AXAC} = \mathbf{POAXAC} + \mathbf{PLAXAC} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWAXAC} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWAXAC} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.210}$$

$$\mathbf{ALPAC} = \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} \cdot \left[\mathbf{POALPAC} + \mathbf{PLALPAC} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWALPAC} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWALPAC} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right] \tag{3.211}$$

$$\mathbf{ALP1AC} = \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} \cdot \left[\mathbf{POALP1AC} + \mathbf{PLALP1AC} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWALP1AC} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWALP1AC} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right] \tag{3.212}$$

$$\mathbf{CGOV} = \frac{W_{\mathrm{E,CV}}}{W_{\mathrm{EN}}} \cdot \left[\mathbf{POCGOV} + \mathbf{PLCGOV} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWCGOV} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWCGOV} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right] \tag{3.213}$$

$$\mathbf{CGOVD} = \frac{W_{\mathrm{E,CV}}}{W_{\mathrm{EN}}} \cdot \left[\mathbf{POCGOVD} + \mathbf{PLCGOVD} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWCGOVD} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWCGOVD} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right] \tag{3.214}$$

$$\mathbf{CGBOV} = \frac{L_{\mathrm{G,CV}}}{L_{\mathrm{EN}}} \cdot \left[\mathbf{POCGBOV} + \mathbf{PLCGBOV} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWCGBOV} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWCGBOV} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right] \tag{3.215}$$

$$\mathbf{CINR} = \frac{W_{\mathrm{E,CV}}}{W_{\mathrm{EN}}} \cdot \left[\mathbf{POCINR} + \mathbf{PLCINR} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWCINR} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWCINR} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right] \tag{3.216}$$

$$\mathbf{CINRD} = \frac{W_{\mathrm{E,CV}}}{W_{\mathrm{EN}}} \cdot \Bigg[\mathbf{POCINRD} + \mathbf{PLCINRD} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWCINRD} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWCINRD} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\Bigg] \quad (3.217)$$

$$\mathbf{CFR} = \frac{W_{\mathrm{G,CV}}}{W_{\mathrm{EN}}} \cdot \Bigg[\mathbf{POCFR} + \mathbf{PLCFR} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWCFR} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWCFR} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\Bigg] \quad (3.218)$$

$$\mathbf{CFRD} = \frac{W_{\mathrm{G,CV}}}{W_{\mathrm{EN}}} \cdot \Bigg[\mathbf{POCFRD} + \mathbf{PLCFRD} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWCFRD} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWCFRD} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\Bigg] \quad (3.219)$$

Noise Model Parameters

$$\mathbf{FNTEXC} = \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^2 \cdot \Bigg[\mathbf{POFNTEXC} + \mathbf{PLFNTEXC} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWFNTEXC} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWFNTEXC} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\Bigg] \quad (3.220)$$

$$\mathbf{NFA} = \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \cdot \Bigg[\mathbf{PONFA} + \mathbf{PLNFA} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWNFA} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWNFA} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\Bigg] \quad (3.221)$$

$$\mathbf{NFB} = \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \cdot \Bigg[\mathbf{PONFB} + \mathbf{PLNFB} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWNFB} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWNFB} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\Bigg] \quad (3.222)$$

$$\mathbf{NFC} = \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \cdot \Bigg[\mathbf{PONFC} + \mathbf{PLNFC} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWNFC} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWNFC} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\Bigg] \quad (3.223)$$

Edge Transistor Parameters

$$W_{\mathrm{E,edge}} = 2 \cdot \mathbf{WEDGE} + \mathbf{WEDGEW} \cdot W_{\mathrm{E}} \quad (3.224)$$

$$\mathbf{VFBEDGE} = \mathbf{POVFBEDGE} + \mathbf{PLVFBEDGE} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWVFBEDGE} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWVFBEDGE} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \quad (3.225)$$

$$\mathbf{STVFBEDGE} = \mathbf{POSTVFBEDGE} + \mathbf{PLSTVFBEDGE} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWSTVFBEDGE} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWSTVFBEDGE} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \quad (3.226)$$

$$\mathbf{NEFFEDGE} = \mathbf{PONEFFEDGE} + \mathbf{PLNEFFEDGE} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWNEFFEDGE} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWNEFFEDGE} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.227}$$

$$\mathbf{CTEDGE} = \mathbf{POCTEDGE} + \mathbf{PLCTEDGE} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWCTEDGE} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWCTEDGE} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.228}$$

$$\mathbf{BETNEDGE} = \frac{W_{\mathrm{E,edge}}}{L_{\mathrm{E}}} \cdot \left[\mathbf{POBETNEDGE} + \mathbf{PLBETNEDGE} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWBETNEDGE} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWBETNEDGE} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right] \tag{3.229}$$

$$\mathbf{STBETEDGE} = \mathbf{POSTBETEDGE} + \mathbf{PLSTBETEDGE} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWSTBETEDGE} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWSTBETEDGE} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.230}$$

$$\mathbf{PSCEEDGE} = \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^2 \cdot \left[\mathbf{POPSCEEDGE} + \mathbf{PLPSCEEDGE} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWPSCEEDGE} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWPSCEEDGE} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right] \tag{3.231}$$

$$\mathbf{PSCEBEDGE} = \mathbf{POPSCEBEDGE} + \mathbf{PLPSCEBEDGE} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWPSCEBEDGE} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWPSCEBEDGE} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.232}$$

$$\mathbf{PSCEDEDGE} = \mathbf{POPSCEDEDGE} + \mathbf{PLPSCEDEDGE} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWPSCEDEDGE} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWPSCEDEDGE} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.233}$$

$$\mathbf{CFEDGE} = \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^2 \cdot \left[\mathbf{POCFEDGE} + \mathbf{PLCFEDGE} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWCFEDGE} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWCFEDGE} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}}\right] \tag{3.234}$$

$$\mathbf{CFDEDGE} = \mathbf{POCFDEDGE} + \mathbf{PLCFDEDGE} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWCFDEDGE} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWCFDEDGE} \cdot \frac{A_{\mathrm{EN}}}{A_{\mathrm{E}}} \tag{3.235}$$

$$\mathbf{CFBEDGE} = \mathbf{POCFBEDGE} + \mathbf{PLCFBEDGE} \cdot \frac{L_{\rm EN}}{L_{\rm E}} + \mathbf{PWCFBEDGE} \cdot \frac{W_{\rm EN}}{W_{\rm E}} + \mathbf{PLWCFBEDGE} \cdot \frac{A_{\rm EN}}{A_{\rm E}} \tag{3.236}$$

$$\mathbf{NFAEDGE} = \frac{A_{\rm EN}}{L_{\rm E} \cdot W_{\rm E,edge}} \cdot \left[\mathbf{PONFAEDGE} + \mathbf{PLNFAEDGE} \cdot \frac{L_{\rm EN}}{L_{\rm E}} + \mathbf{PWNFAEDGE} \cdot \frac{W_{\rm EN}}{W_{\rm E}} + \mathbf{PLWNFAEDGE} \cdot \frac{A_{\rm EN}}{A_{\rm E}}\right] \tag{3.237}$$

$$\mathbf{NFBEDGE} = \frac{A_{\rm EN}}{L_{\rm E} \cdot W_{\rm E,edge}} \cdot \left[\mathbf{PONFBEDGE} + \mathbf{PLNFBEDGE} \cdot \frac{L_{\rm EN}}{L_{\rm E}} + \mathbf{PWNFBEDGE} \cdot \frac{W_{\rm EN}}{W_{\rm E}} + \mathbf{PLWNFBEDGE} \cdot \frac{A_{\rm EN}}{A_{\rm E}}\right] \tag{3.238}$$

$$\mathbf{NFCEDGE} = \frac{A_{\rm EN}}{L_{\rm E} \cdot W_{\rm E,edge}} \cdot \left[\mathbf{PONFCEDGE} + \mathbf{PLNFCEDGE} \cdot \frac{L_{\rm EN}}{L_{\rm E}} + \mathbf{PWNFCEDGE} \cdot \frac{W_{\rm EN}}{W_{\rm E}} + \mathbf{PLWNFCEDGE} \cdot \frac{A_{\rm EN}}{A_{\rm E}}\right] \tag{3.239}$$

Self Heating Effect Parameters

$$\mathbf{RTH} = \frac{A_{\rm EN}}{A_{\rm E}} \cdot \left[\mathbf{PORTH} + \mathbf{PLRTH} \cdot \frac{L_{\rm EN}}{L_{\rm E}} + \mathbf{PWRTH} \cdot \frac{W_{\rm EN}}{W_{\rm E}} + \mathbf{PLWRTH} \cdot \frac{A_{\rm EN}}{A_{\rm E}}\right] \tag{3.240}$$

$$\mathbf{CTH} = \frac{A_{\rm EN}}{A_{\rm E}} \cdot \left[\mathbf{POCTH} + \mathbf{PLCTH} \cdot \frac{L_{\rm EN}}{L_{\rm E}} + \mathbf{PWCTH} \cdot \frac{W_{\rm EN}}{W_{\rm E}} + \mathbf{PLWCTH} \cdot \frac{A_{\rm EN}}{A_{\rm E}}\right] \tag{3.241}$$

$$\mathbf{STRTH} = \mathbf{POSTRTH} + \mathbf{PLSTRTH} \cdot \frac{L_{\rm EN}}{L_{\rm E}} + \mathbf{PWSTRTH} \cdot \frac{W_{\rm EN}}{W_{\rm E}} + \mathbf{PLWSTRTH} \cdot \frac{A_{\rm EN}}{A_{\rm E}} \tag{3.242}$$

NQS parameters

$$\mathbf{MUNQS} = \mathbf{POMUNQS} + \mathbf{PLMUNQS} \cdot \frac{L_{\rm EN}}{L_{\rm E}} + \mathbf{PWMUNQS} \cdot \frac{W_{\rm EN}}{W_{\rm E}} + \mathbf{PLWMUNQS} \cdot \frac{A_{\rm EN}}{A_{\rm E}} \tag{3.243}$$

3.5 Parasitic resistances

PSP model contains a network of parasitic elements: a gate resistance, two diffusion resistances for source and drain, and four bulk resistances. Note that the junction diodes are no longer directly connected to the bulk terminal of the intrinsic MOS-transistor. The complete circuit is shown in Fig. 3.2. At this moment, only the gate resistance is scaled with geometry (facilitating the implementation of multi-finger devices).

Note: The resistance equations are calculated when **SWGEO** $= 1$.

$$L_\mathrm{f} = L + \Delta L_\mathrm{PS} \tag{3.244}$$

$$L_\mathrm{sil,f} = L_\mathrm{f} + \mathbf{DLSIL} \tag{3.245}$$

$$W_\mathrm{E,f} = W_\mathrm{f} + \Delta W_\mathrm{OD} \tag{3.246}$$

$$X_\mathrm{GWE} = \mathbf{XGW} - 0.5 \cdot \Delta W_\mathrm{OD} \tag{3.247}$$

$$\mathbf{RG} = \mathbf{RGO} + \frac{1}{\mathbf{NF}} \cdot \left[\frac{\mathbf{RSHG} \cdot \left(\frac{W_\mathrm{E,f}}{3 \cdot \mathbf{NGCON}} + X_\mathrm{GWE} \right)}{\mathbf{NGCON} \cdot L_\mathrm{sil,f}} + \frac{\mathbf{RINT} + \mathbf{RVPOLY}}{W_\mathrm{E,f} \cdot L_\mathrm{f}} \right] \tag{3.248}$$

$$\mathbf{RSE} = \mathbf{NRS} \cdot \mathbf{RSH} \tag{3.249}$$

$$\mathbf{RDE} = \mathbf{NRD} \cdot \mathbf{RSHD} \tag{3.250}$$

$$\mathbf{RBULK} = \mathbf{RBULKO} \tag{3.251}$$

$$\mathbf{RWELL} = \mathbf{RWELLO} \tag{3.252}$$

$$\mathbf{RJUNS} = \mathbf{RJUNSO} \tag{3.253}$$

$$\mathbf{RJUND} = \mathbf{RJUNDO} \tag{3.254}$$

Note: The values of L_f, $L_\mathrm{sil,f}$, $W_\mathrm{E,f}$ and X_GWE are clipped to a minimum value of 1 nm. The calculated local parameters are subject to the boundaries specified in Section 2.5.8.

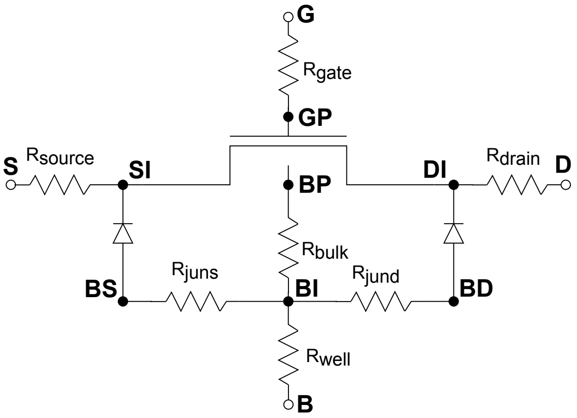

Figure 3.2: Parasitics circuit: $\mathrm{R_{gate}}$ = **RG**, $\mathrm{R_{source}}$ = **RSE**, $\mathrm{R_{drain}}$ = **RDE**, $\mathrm{R_{bulk}}$ = **RBULK**, $\mathrm{R_{well}}$ = **RWELL**, $\mathrm{R_{juns}}$ = **RJUNS**, $\mathrm{R_{jund}}$ = **RJUND**

3.6 Stress effects

The stress model of BSIM4.4.0 [3] has been adopted in PSP without any modifications, except for two changes: (1) in the original BSIM parameter names all zeros have been replaced by "O"s, in order to comply with PSP conventions and (2) the BSIM parameters *STK2* and *LODK2* are not available in PSP. Some trivial conversion of parameters BSIM→PSP is still necessary, see [2].

The local PSP parameters affected by the stress equations are **BETN**, **THESAT**, **THESATAC**, **VFB**, **CF**, **BETNEDGE**, **VFBEDGE** and **CFEDGE**.

Calculation of **SA** and **SB** for irregular layouts is given in Section B.1.

Note:

- After modification of the local parameters by the stress equations, clipping is applied according to Section 2.5.2.
- If both **SA** and **SB** are set to 0, the stress-equations are *not* computed.
- The stress equations are calculated when **SWGEO** $= 1$.

3.6.1 Layout effects for multi-finger devices

For multi-finger devices, effective values $\mathbf{SA}_{\mathrm{eff}}$ and $\mathbf{SB}_{\mathrm{eff}}$ for the instance parameters are calculated (see Fig. 3.3).

$$\frac{1}{\mathbf{SA}_{\mathrm{eff}} + 0.5 \cdot L} = \frac{1}{\mathbf{NF}} \cdot \sum_{i=0}^{\mathbf{NF}-1} \frac{1}{\mathbf{SA} + 0.5 \cdot L + i \cdot (\mathbf{SD} + L)} \tag{3.255}$$

$$\frac{1}{\mathbf{SB}_{\mathrm{eff}} + 0.5 \cdot L} = \frac{1}{\mathbf{NF}} \cdot \sum_{i=0}^{\mathbf{NF}-1} \frac{1}{\mathbf{SB} + 0.5 \cdot L + i \cdot (\mathbf{SD} + L)} \tag{3.256}$$

3.6.2 Layout effects for regular shapes

$$R_{\mathrm{A}} = \frac{1}{\mathbf{SA}_{\mathrm{eff}} + 0.5 \cdot L} \tag{3.257}$$

$$R_{\mathrm{B}} = \frac{1}{\mathbf{SB}_{\mathrm{eff}} + 0.5 \cdot L} \tag{3.258}$$

$$R_{\mathrm{A,ref}} = \frac{1}{\mathbf{SAREF} + 0.5 \cdot L} \tag{3.259}$$

$$R_{\mathrm{B,ref}} = \frac{1}{\mathbf{SBREF} + 0.5 \cdot L} \tag{3.260}$$

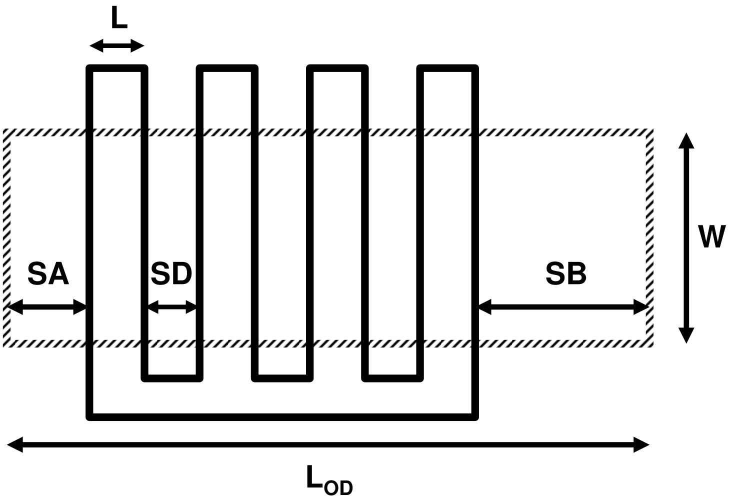

Figure 3.3: A typical layout of multi-finger devices with an additional instance parameters **SD**.

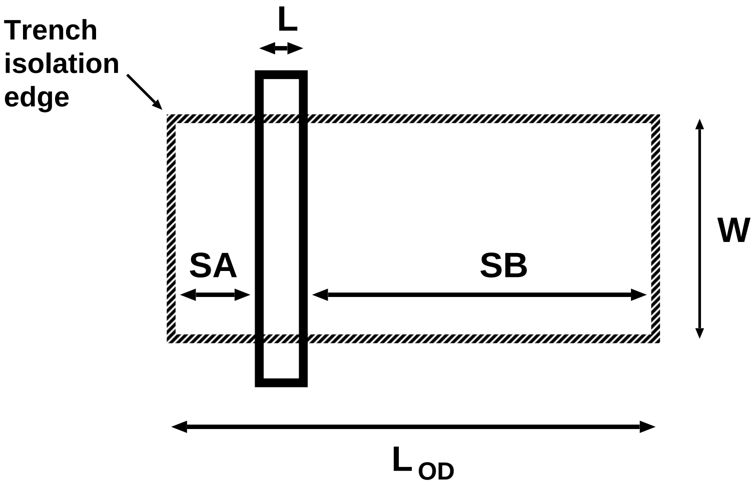

Figure 3.4: Typical layout of a MOSFET. Note that $L_{\mathrm{OD}} = \mathbf{SA} + \mathbf{SB} + L$, where OD is the active region definition.

3.6.3 Parameter modifications

Mobility-related equations

$$K_{\mathrm{u0}} = \left(1 + \frac{\mathbf{LKUO}}{(L+\Delta L_{\mathrm{PS}})^{\mathbf{LLODKUO}}} + \frac{\mathbf{WKUO}}{(W_{\mathrm{f}}+\Delta W_{\mathrm{OD}}+\mathbf{WLOD})^{\mathbf{WLODKUO}}} + \frac{\mathbf{PKUO}}{(L+\Delta L_{\mathrm{PS}})^{\mathbf{LLODKUO}}\cdot(W_{\mathrm{f}}+\Delta W_{\mathrm{OD}}+\mathbf{WLOD})^{\mathbf{WLODKUO}}}\right) \cdot \left[1 + \mathbf{TKUO}\cdot\left(\frac{T_{\mathrm{KA}}}{T_{\mathrm{KR}}}-1\right)\right] \tag{3.261}$$

$$\rho_\beta = \frac{\mathbf{KUO}}{K_{\mathrm{u0}}}\cdot(R_{\mathrm{A}}+R_{\mathrm{B}}) \tag{3.262}$$

$$\rho_{\beta,\mathrm{ref}} = \frac{\mathbf{KUO}}{K_{\mathrm{u0}}}\cdot(R_{\mathrm{A,ref}}+R_{\mathrm{B,ref}}) \tag{3.263}$$

$$\mathbf{BETN} = \frac{1+\rho_\beta}{1+\rho_{\beta,\mathrm{ref}}}\cdot\mathbf{BETN}_{\mathrm{ref}} \tag{3.264}$$

$$\mathbf{THESAT} = \frac{1+\rho_\beta}{1+\rho_{\beta,\mathrm{ref}}}\cdot\frac{1+\mathbf{KVSAT}\cdot\rho_{\beta,\mathrm{ref}}}{1+\mathbf{KVSAT}\cdot\rho_\beta}\cdot\mathbf{THESAT}_{\mathrm{ref}} \tag{3.265}$$

$$\mathbf{THESATAC} = \frac{1+\rho_\beta}{1+\rho_{\beta,\mathrm{ref}}}\cdot\frac{1+\mathbf{KVSATAC}\cdot\rho_{\beta,\mathrm{ref}}}{1+\mathbf{KVSATAC}\cdot\rho_\beta}\cdot\mathbf{THESATAC}_{\mathrm{ref}} \tag{3.266}$$

$$\mathbf{BETNEDGE} = \frac{1+\rho_\beta}{1+\rho_{\beta,\mathrm{ref}}}\cdot\mathbf{BETNEDGE}_{\mathrm{ref}} \tag{3.267}$$

Threshold-voltage-related equations

$$K_{\mathrm{vth0}} = 1 + \frac{\mathbf{LKVTHO}}{(L+\Delta L_{\mathrm{PS}})^{\mathbf{LLODVTH}}} + \frac{\mathbf{WKVTHO}}{(W_{\mathrm{f}}+\Delta W_{\mathrm{OD}}+\mathbf{WLOD})^{\mathbf{WLODVTH}}} + \frac{\mathbf{PKVTHO}}{(L+\Delta L_{\mathrm{PS}})^{\mathbf{LLODVTH}}\cdot(W_{\mathrm{f}}+\Delta W_{\mathrm{OD}}+\mathbf{WLOD})^{\mathbf{WLODVTH}}} \tag{3.268}$$

$$\Delta R = R_{\mathrm{A}}+R_{\mathrm{B}}-R_{\mathrm{A,ref}}-R_{\mathrm{B,ref}} \tag{3.269}$$

$$\mathbf{VFB} = \mathbf{VFB}_{\mathrm{ref}} + \mathbf{KVTHO}\cdot\frac{\Delta R}{K_{\mathrm{vth0}}} \tag{3.270}$$

$$\mathbf{CF} = \mathbf{CF}_{\mathrm{ref}} + \mathbf{STETAO}\cdot\frac{\Delta R}{K_{\mathrm{vth0}}^{\mathbf{LODETAO}}} \tag{3.271}$$

$$\mathbf{VFBEDGE} = \mathbf{VFBEDGE}_{\mathrm{ref}} + \mathbf{KVTHO}\cdot\frac{\Delta R}{K_{\mathrm{vth0}}} \tag{3.272}$$

$$\mathbf{CFEDGE} = \mathbf{CFEDGE}_{\mathrm{ref}} + \mathbf{STETAO}\cdot\frac{\Delta R}{K_{\mathrm{vth0}}^{\mathbf{LODETAO}}} \tag{3.273}$$

3.7 Well proximity effects

The well proximity effect (WPE) model from BSIM4.5.0 [4, 5, 6] has been adopted in PSP with two changes relative to BSIM4.5.0: (1) in the original BSIM parameter names all zeros have been replaced by 'O's in order to comply with PSP naming convention and (2) the BSIM parameter *K2WE* is not available in PSP. Except for some trivial conversion of parameters BSIM→PSP [2], WPE parameters from BSIM can be used directly in PSP.

The local PSP parameters affected by the WPE equations are **VFB**, **BETN**, **VFBEDGE** and **BETNEDGE**

How to calculate **SCA**, **SCB**, and **SCC** is shown in Section B.2.

Note:

- After modification of the local parameters by the WPE equations, clipping is applied according to Section 2.5.2.
- If **SCA**, **SCB**, **SCC** and **SC** are all set to 0, the WPE equations are *not* computed.
- The WPE equations are calculated when **SWGEO** $= 1$.

3.7.1 Parameters for pre-layout simulation

If **SCA** $=$ **SCB** $=$ **SCC** $= 0$ and **SC** > 0, **SCA**, **SCB**, and **SCC** will be computed from **SC** according to Eqs. (B.9)–(B.11), as shown below. Here, **SC** should be taken as the distance to the nearest well edge (see Fig. 3.5). If any of the parameters **SCA**, **SCB**, or **SCC** is positive, all three values as supplied will be used and **SC** will be ignored.

If **SCA** $=$ **SCB** $=$ **SCC** $= 0$ and **SC** > 0

$$\mathbf{SCA} = \frac{\mathbf{SCREF}^2}{W_\mathrm{f}} \cdot \left(\frac{1}{\mathbf{SC}} - \frac{1}{\mathbf{SC} + W_\mathrm{f}}\right) \tag{3.274}$$

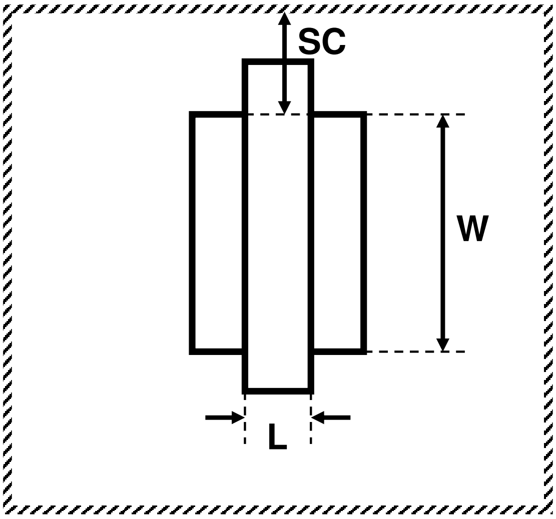

Figure 3.5: A layout of MOS devices for pre-layout simulation using estimated value for **SC**.

$$\mathbf{SCB} = \frac{1}{W_\mathrm{f} \cdot \mathbf{SCREF}} \cdot \left[\frac{\mathbf{SCREF}}{10} \cdot \mathbf{SC} \cdot \exp\left(-10 \cdot \frac{\mathbf{SC}}{\mathbf{SCREF}}\right) + \frac{\mathbf{SCREF}^2}{100} \cdot \exp\left(-10 \cdot \frac{\mathbf{SC}}{\mathbf{SCREF}}\right) \right.$$
$$- \frac{\mathbf{SCREF}}{10} \cdot (\mathbf{SC} + W_\mathrm{f}) \cdot \exp\left(-10 \cdot \frac{\mathbf{SC} + W_\mathrm{f}}{\mathbf{SCREF}}\right)$$
$$\left. - \frac{\mathbf{SCREF}^2}{100} \cdot \exp\left(-10 \cdot \frac{\mathbf{SC} + W_\mathrm{f}}{\mathbf{SCREF}}\right) \right] \tag{3.275}$$

$$\mathbf{SCC} = \frac{1}{W_\mathrm{f} \cdot \mathbf{SCREF}} \cdot \left[\frac{\mathbf{SCREF}}{20} \cdot \mathbf{SC} \cdot \exp\left(-20 \cdot \frac{\mathbf{SC}}{\mathbf{SCREF}}\right) + \frac{\mathbf{SCREF}^2}{400} \cdot \exp\left(-20 \cdot \frac{\mathbf{SC}}{\mathbf{SCREF}}\right) \right.$$
$$- \frac{\mathbf{SCREF}}{20} \cdot (\mathbf{SC} + W_\mathrm{f}) \cdot \exp\left(-20 \cdot \frac{\mathbf{SC} + W_\mathrm{f}}{\mathbf{SCREF}}\right)$$
$$\left. - \frac{\mathbf{SCREF}^2}{400} \cdot \exp\left(-20 \cdot \frac{\mathbf{SC} + W_\mathrm{f}}{\mathbf{SCREF}}\right) \right] \tag{3.276}$$

3.7.2 Calculation of parameter modifications

$$K_\mathrm{vthowe} = \mathbf{KVTHOWEO} + \mathbf{KVTHOWEL} \cdot \frac{L_\mathrm{EN}}{L_\mathrm{E}} +$$
$$\mathbf{KVTHOWEW} \cdot \frac{W_\mathrm{EN}}{W_\mathrm{E}} + \mathbf{KVTHOWELW} \cdot \frac{A_\mathrm{EN}}{A_\mathrm{E}} \tag{3.277}$$

$$K_\mathrm{uowe} = \mathbf{KUOWEO} + \mathbf{KUOWEL} \cdot \frac{L_\mathrm{EN}}{L_\mathrm{E}} + \mathbf{KUOWEW} \cdot \frac{W_\mathrm{EN}}{W_\mathrm{E}} + \mathbf{KUOWELW} \cdot \frac{A_\mathrm{EN}}{A_\mathrm{E}} \tag{3.278}$$

$$\mathbf{VFB} = \mathbf{VFB}_\mathrm{ref} + K_\mathrm{vthowe} \cdot (\mathbf{SCA} + \mathbf{WEB} \cdot \mathbf{SCB} + \mathbf{WEC} \cdot \mathbf{SCC}) \tag{3.279}$$

$$\mathbf{BETN} = \mathbf{BETN}_\mathrm{ref} \cdot [1 + K_\mathrm{uowe} \cdot (\mathbf{SCA} + \mathbf{WEB} \cdot \mathbf{SCB} + \mathbf{WEC} \cdot \mathbf{SCC})] \tag{3.280}$$

$$\mathbf{VFBEDGE} = \mathbf{VFBEDGE}_\mathrm{ref} + K_\mathrm{vthowe} \cdot (\mathbf{SCA} + \mathbf{WEB} \cdot \mathbf{SCB} + \mathbf{WEC} \cdot \mathbf{SCC}) \tag{3.281}$$

$$\mathbf{BETNEDGE} = \mathbf{BETNEDGE}_\mathrm{ref} \cdot [1 + K_\mathrm{uowe} \cdot (\mathbf{SCA} + \mathbf{WEB} \cdot \mathbf{SCB} + \mathbf{WEC} \cdot \mathbf{SCC})] \tag{3.282}$$

3.8 Asymmetric junctions

Asymmetric junctions can be modeled in PSP. This includes asymmetric source-bulk and drain-bulk junctions, GIDL/GISL, overlap gate currents, overlap capacitances and outer fringe capacitances. The asymmetric junction model can be switched on by means of the parameter **SWJUNASYM**. Note that if **SWJUNASYM** $= 1$, the new parameters for the drain side are used all together. Those whose values are not explicitly specified in the model card are set to their default value, *not* to their counterparts for the source side. In other words, it is not possible to activate the parameters for the drain side on a one-by-one basis. The physical scaling and binning rules to calculate the related local parameters for the drain side are given in Section 3.3 and 3.4.

If **SWJUNASYM** $= 0$, the related parameters for the drain side are ignored. Effectively, the following assignments are applied before evaluation of the calculations described in Section 4.

If **SWJUNASYM** $= 0$:

$$\mathbf{TOXOVD} = \mathbf{TOXOV} \tag{3.283}$$

$$\mathbf{NOVD} = \mathbf{NOV} \tag{3.284}$$

$$\mathbf{AGIDLD} = \mathbf{AGIDL} \tag{3.285}$$

$$\mathbf{BGIDLD} = \mathbf{BGIDL} \tag{3.286}$$

$$\mathbf{STBGIDLD} = \mathbf{STBGIDL} \tag{3.287}$$

$$\mathbf{CGIDLD} = \mathbf{CGIDL} \tag{3.288}$$

$$\mathbf{IGOVD} = \mathbf{IGOV} \tag{3.289}$$

$$\mathbf{CGOVD} = \mathbf{CGOV} \tag{3.290}$$

$$\mathbf{FCGOVACCD} = \mathbf{FCGOVACC} \tag{3.291}$$

$$\mathbf{CINRD} = \mathbf{CINR} \tag{3.292}$$

$$\mathbf{CFRD} = \mathbf{CFR} \tag{3.293}$$

$$\mathbf{RSHD} = \mathbf{RSH} \tag{3.294}$$

Section 4

PSP Model Equations

4.1 Internal Parameters (including Temperature Scaling)

In this section, bias-independent internal parameters will be calculated, including temperature scaling. These parameters are computed from local parameters. Local parameters are (as usual) denoted by capital characters in bold font, whereas the internal parameters are denoted by symbols in bold font.

Transistor temperatures

$$T_{\mathrm{KR}} = T_0 + \mathbf{TR} \tag{4.1}$$

Note: if the parameter **TREF** is defined, **TR** is replaced by **TREF**.

$$T_{\mathrm{KA}} = T_0 + T_{\mathrm{A}} + \mathbf{DTA} + \mathbf{TRISE} \tag{4.2}$$

Note: if the parameter **DTEMP** is defined, **TRISE** is replaced by **DTEMP**.

$$T_{\mathrm{KD}} = T_{\mathrm{KA}} + V_{\mathrm{dt}} \tag{4.3}$$

$$\Delta T = T_{\mathrm{KD}} - T_{\mathrm{KR}} \tag{4.4}$$

$$\Delta T_{\mathrm{A}} = T_{\mathrm{KA}} - T_{\mathrm{KR}} \tag{4.5}$$

$$\boldsymbol{\phi}_{\mathbf{T}} = \frac{k_{\mathrm{B}} \cdot T_{\mathrm{KD}}}{q} \tag{4.6}$$

$$\boldsymbol{\phi}_{\mathbf{T}_{\mathrm{A}}} = \frac{k_{\mathrm{B}} \cdot T_{\mathrm{KA}}}{q} \tag{4.7}$$

Local process parameters

$$\boldsymbol{V}_{\mathbf{FB}} = \mathbf{VFB} + \mathbf{STVFB} \cdot \Delta T \cdot (1 + \mathbf{ST2VFB} \cdot \Delta T) + \mathbf{DELVTO} \tag{4.8}$$

$$E_{\mathrm{g}}/q = 1.179 - 9.025 \cdot 10^{-5} \cdot T_{\mathrm{KD}} - 3.05 \cdot 10^{-7} \cdot {T_{\mathrm{KD}}}^2 \tag{4.9}$$

$$r_{\mathrm{T}} = \left(1.045 + 4.5 \cdot 10^{-4} \cdot T_{\mathrm{KD}}\right) \cdot \left(0.523 + 1.4 \cdot 10^{-3} \cdot T_{\mathrm{KD}} - 1.48 \cdot 10^{-6} \cdot {T_{\mathrm{KD}}}^2\right) \tag{4.10}$$

$$n_\mathrm{i} = 2.5 \cdot 10^{25} \cdot {r_\mathrm{T}}^{3/4} \cdot (T_\mathrm{KD}/300)^{3/2} \cdot \exp\left(-\frac{E_\mathrm{g}/q}{2 \cdot \boldsymbol{\phi_\mathrm{T}}}\right) \tag{4.11}$$

$$\phi^\mathrm{cl}_\mathrm{B,dc} = \mathrm{MAX}\left(\textbf{DPHIB} + 2 \cdot \boldsymbol{\phi_\mathrm{T}} \cdot \ln\left[\textbf{NEFF}/n_\mathrm{i}\right],\, 0.05\right) \tag{4.12}$$

$$N_\mathrm{eff,ac} = \mathrm{MIN}[\mathrm{MAX}(\textbf{FACNEFFAC} \cdot \textbf{NEFF}, 10^{20}), 10^{26}] \tag{4.13}$$

$$\phi^\mathrm{cl}_\mathrm{B,ac} = \mathrm{MAX}\left(\textbf{DPHIB} + \textbf{DELVTAC} + 2 \cdot \boldsymbol{\phi_\mathrm{T}} \cdot \ln\left[N_\mathrm{eff,ac}/n_\mathrm{i}\right],\, 0.05\right) \tag{4.14}$$

$$\epsilon_\mathrm{ox} = \textbf{EPSROX} \cdot \epsilon_0 \tag{4.15}$$

$$C_\mathrm{ox} = \epsilon_\mathrm{ox}/\textbf{TOX} \tag{4.16}$$

$$\epsilon_\mathrm{Si} = \epsilon_\mathrm{r,Si} \cdot \epsilon_0 \tag{4.17}$$

$$\gamma_\mathrm{0,dc} = \sqrt{2 \cdot q \cdot \epsilon_\mathrm{Si} \cdot \textbf{NEFF}}/C_\mathrm{ox} \tag{4.18}$$

$$\gamma_\mathrm{0,ac} = \sqrt{2 \cdot q \cdot \epsilon_\mathrm{Si} \cdot N_\mathrm{eff,ac}}/C_\mathrm{ox} \tag{4.19}$$

$$G^\mathrm{cl}_\mathrm{0,dc} = \gamma_\mathrm{0,dc}/\sqrt{\boldsymbol{\phi_\mathrm{T}}} \tag{4.20}$$

$$G^\mathrm{cl}_\mathrm{0,ac} = \gamma_\mathrm{0,ac}/\sqrt{\boldsymbol{\phi_\mathrm{T}}} \tag{4.21}$$

Interface states parameters

$$\boldsymbol{C_\mathrm{T}} = \textbf{CT} \cdot (T_\mathrm{KR}/T_\mathrm{KD})^{\textbf{STCT}} \tag{4.22}$$

$$\boldsymbol{C_\mathrm{TG}} = \textbf{CTG} \cdot (T_\mathrm{KD}/T_\mathrm{KR}) \tag{4.23}$$

Polysilicon depletion parameters

$$\boldsymbol{k_\mathrm{P}} = \begin{cases} \text{if } \textbf{NP} = 0 & \left\{ \boldsymbol{k_\mathrm{P}} = 0 \right. \\ \text{if } \textbf{NP} > 0 & \begin{cases} \mathrm{NP}_1 = \mathrm{MAX}(\textbf{NP},\, 8 \cdot 10^7/\textbf{TOX}^2) \\ \mathrm{NP}_2 = \mathrm{MAX}(\mathrm{NP}_1,\, 5 \cdot 10^{24}) \\ \boldsymbol{k_\mathrm{P}} = 2 \cdot \boldsymbol{\phi_\mathrm{T}} \cdot C^2_\mathrm{ox}/(q \cdot \epsilon_\mathrm{Si} \cdot \mathrm{NP}_2) \end{cases} \end{cases} \tag{4.24}$$

Quantum-mechanical correction parameters

$$\boldsymbol{q_\mathrm{lim}} = 10 \cdot \boldsymbol{\phi_\mathrm{T}} \tag{4.25}$$

$$\boldsymbol{q_\mathrm{q}} = \begin{cases} 0.4 \cdot \textbf{QMC} \cdot QM_\mathrm{N} \cdot C^{2/3}_\mathrm{ox} & \text{for NMOS} \\ 0.4 \cdot \textbf{QMC} \cdot QM_\mathrm{P} \cdot C^{2/3}_\mathrm{ox} & \text{for PMOS} \end{cases} \tag{4.26}$$

$$q_\mathrm{b0,dc} = \gamma_\mathrm{0,dc} \cdot \sqrt{\phi^\mathrm{cl}_\mathrm{B,dc}} \tag{4.27}$$

$$q_\mathrm{b0,ac} = \gamma_\mathrm{0,ac} \cdot \sqrt{\phi^\mathrm{cl}_\mathrm{B,ac}} \tag{4.28}$$

$$\boldsymbol{\phi_{\mathrm{B,dc}}} = \phi_{\mathrm{B,dc}}^{\mathrm{cl}} + 0.75 \cdot \boldsymbol{q_{\mathrm{q}}} \cdot q_{\mathrm{b0,dc}}^{2/3} \tag{4.29}$$

$$\boldsymbol{\phi_{\mathrm{B,ac}}} = \phi_{\mathrm{B,ac}}^{\mathrm{cl}} + 0.75 \cdot \boldsymbol{q_{\mathrm{q}}} \cdot q_{\mathrm{b0,ac}}^{2/3} \tag{4.30}$$

$$\boldsymbol{G_{\mathrm{0,dc}}} = G_{\mathrm{0,dc}}^{\mathrm{cl}} \cdot \left(1 + \boldsymbol{q_{\mathrm{q}}} \cdot q_{\mathrm{b0,dc}}^{-1/3}\right) \tag{4.31}$$

$$\boldsymbol{G_{\mathrm{0,ac}}} = G_{\mathrm{0,ac}}^{\mathrm{cl}} \cdot \left(1 + \boldsymbol{q_{\mathrm{q}}} \cdot q_{\mathrm{b0,ac}}^{-1/3}\right) \tag{4.32}$$

V_{SB}**-clipping parameters**

$$\boldsymbol{\phi_{\mathrm{X,dc}}} = 0.95 \cdot \boldsymbol{\phi_{\mathrm{B,dc}}} \tag{4.33}$$

$$\boldsymbol{\phi_{\mathrm{X,ac}}} = 0.95 \cdot \boldsymbol{\phi_{\mathrm{B,ac}}} \tag{4.34}$$

$$\boldsymbol{\phi^{*}_{\mathrm{X,dc}}} = \mathrm{MINA}\left(\frac{1}{2} \cdot \left(\boldsymbol{\phi_{\mathrm{B,dc}}} + \boldsymbol{\phi_{\mathrm{X,dc}}}\right),\, 0,\, \left(\boldsymbol{\phi_{\mathrm{B,dc}}} - \boldsymbol{\phi_{\mathrm{X,dc}}}\right)^2\right) \tag{4.35}$$

$$\boldsymbol{\phi^{*}_{\mathrm{X,ac}}} = \mathrm{MINA}\left(\frac{1}{2} \cdot \left(\boldsymbol{\phi_{\mathrm{B,ac}}} + \boldsymbol{\phi_{\mathrm{X,ac}}}\right),\, 0,\, \left(\boldsymbol{\phi_{\mathrm{B,ac}}} - \boldsymbol{\phi_{\mathrm{X,ac}}}\right)^2\right) \tag{4.36}$$

NUD parameters

$$u_{\mathrm{s1}} = \sqrt{\mathbf{VSBNUD} + \boldsymbol{\phi_{B}, dc}} - \sqrt{\boldsymbol{\phi_{\mathrm{B,dc}}}} \tag{4.37}$$

$$u_{\mathrm{s21}} = \sqrt{\mathbf{DVSBNUD} + \boldsymbol{\phi_{\mathrm{B,dc}}}} - \sqrt{\boldsymbol{\phi_{\mathrm{B,dc}}}} - u_{\mathrm{s1}} \tag{4.38}$$

Local process parameters in gate overlap regions

$$\gamma_{\mathrm{ov}} = \sqrt{2 \cdot q \cdot \epsilon_{\mathrm{Si}} \cdot \mathbf{NOV}} \cdot \mathbf{TOXOV}/\epsilon_{\mathrm{ox}} \tag{4.39}$$

$$\gamma_{\mathrm{dov}} = \sqrt{2 \cdot q \cdot \epsilon_{\mathrm{Si}} \cdot \mathbf{NOVD}} \cdot \mathbf{TOXOVD}/\epsilon_{\mathrm{ox}} \tag{4.40}$$

$$\boldsymbol{G_{\mathrm{ov}}} = \gamma_{\mathrm{ov}}/\sqrt{\boldsymbol{\phi_{\mathrm{T}}}} \tag{4.41}$$

$$\boldsymbol{G_{\mathrm{dov}}} = \gamma_{\mathrm{dov}}/\sqrt{\boldsymbol{\phi_{\mathrm{T}}}} \tag{4.42}$$

$$\Delta x_{\mathrm{gb,ov,th}} = \frac{\ln\left(exp\left(\mathbf{CGOVACCG} \cdot \frac{0.005}{\boldsymbol{\phi_{\mathrm{T}}}}\right) - 1\right)}{\mathbf{CGOVACCG}} - \ln\left(exp\left(\frac{0.005}{\boldsymbol{\phi_{\mathrm{T}}}}\right) - 1\right) \tag{4.43}$$

$$\boldsymbol{\Delta x_{\mathrm{gb,ov}}} = \ln\left(\boldsymbol{G_{\mathrm{ov}}}/2\right) + \Delta x_{\mathrm{gb,ov,th}} \tag{4.44}$$

$$\boldsymbol{\Delta x_{\mathrm{gb,dov}}} = \ln\left(\boldsymbol{G_{\mathrm{dov}}}/2\right) + \Delta x_{\mathrm{gb,ov,th}} \tag{4.45}$$

$$\boldsymbol{\varepsilon_{\mathrm{ov}}} = 3.1 \cdot \boldsymbol{G_{\mathrm{ov}}} + 8.5 \tag{4.46}$$

$$\boldsymbol{a_{\mathrm{ov}}} = \begin{cases} 64/\boldsymbol{G_{\mathrm{ov}}} & \text{for } 1/\boldsymbol{G_{\mathrm{ov}}} < 0.06 \\ 22/\boldsymbol{G_{\mathrm{ov}}} + 3 & \text{for } 0.06 \leq 1/\boldsymbol{G_{\mathrm{ov}}} \leq 0.45 \\ -7.2/\boldsymbol{G_{\mathrm{ov}}} + 15.5 & \text{for } 0.45 < 1/\boldsymbol{G_{\mathrm{ov}}} \leq 1.6 \\ \boldsymbol{G_{\mathrm{ov}}} & \text{for } 1/\boldsymbol{G_{\mathrm{ov}}} > 1.6 \end{cases} \tag{4.47}$$

$$\boldsymbol{\delta}_{\mathbf{ov}} = \frac{\boldsymbol{\varepsilon}_{\mathbf{ov}}}{2} + \frac{{\boldsymbol{G}_{\mathbf{ov}}}^2}{2} - \boldsymbol{G}_{\mathbf{ov}} \cdot \sqrt{\frac{\boldsymbol{\varepsilon}_{\mathbf{ov}}}{2} + \frac{{\boldsymbol{G}_{\mathbf{ov}}}^2}{4} + \boldsymbol{a}_{\mathbf{ov}}} \tag{4.48}$$

$$\boldsymbol{\varepsilon}_{\mathbf{dov}} = 3.1 \cdot \boldsymbol{G}_{\mathbf{dov}} + 8.5 \tag{4.49}$$

$$\boldsymbol{a}_{\mathbf{dov}} = \begin{cases} 64/\boldsymbol{G}_{\mathbf{dov}} & \text{for } 1/\boldsymbol{G}_{\mathbf{dov}} < 0.06 \\ 22/\boldsymbol{G}_{\mathbf{dov}} + 3 & \text{for } 0.06 \le 1/\boldsymbol{G}_{\mathbf{dov}} \le 0.45 \\ -7.2/\boldsymbol{G}_{\mathbf{dov}} + 15.5 & \text{for } 0.45 < 1/\boldsymbol{G}_{\mathbf{dov}} \le 1.6 \\ \boldsymbol{G}_{\mathbf{dov}} & \text{for } 1/\boldsymbol{G}_{\mathbf{dov}} > 1.6 \end{cases} \tag{4.50}$$

$$\boldsymbol{\delta}_{\mathbf{dov}} = \frac{\varepsilon_{\mathrm{dov}}}{2} + \frac{{\boldsymbol{G}_{\mathbf{dov}}}^2}{2} - \boldsymbol{G}_{\mathbf{dov}} \cdot \sqrt{\frac{\boldsymbol{\varepsilon}_{\mathbf{dov}}}{2} + \frac{{\boldsymbol{G}_{\mathbf{dov}}}^2}{4} + \boldsymbol{a}_{\mathbf{dov}}} \tag{4.51}$$

Mobility parameters

$$\boldsymbol{\beta} = \mathbf{FACTUO} \cdot \mathbf{BETN} \cdot C_{\mathrm{ox}} \cdot (T_{\mathrm{KR}}/T_{\mathrm{KD}})^{\mathbf{STBET}} \tag{4.52}$$

$$\boldsymbol{\theta}_{\boldsymbol{\mu}} = \mathbf{THEMU} \cdot (T_{\mathrm{KR}}/T_{\mathrm{KD}})^{\mathbf{STTHEMU}} \tag{4.53}$$

$$\boldsymbol{\mu}_{\mathbf{E}} = \mathbf{MUE} \cdot (T_{\mathrm{KR}}/T_{\mathrm{KD}})^{\mathbf{STMUE}} \tag{4.54}$$

$$\boldsymbol{X}_{\mathbf{cor}} = \mathbf{XCOR} \cdot (T_{\mathrm{KR}}/T_{\mathrm{KD}})^{\mathbf{STXCOR}} \tag{4.55}$$

$$\boldsymbol{C}_{\mathbf{S}} = \mathbf{CS} \cdot (T_{\mathrm{KR}}/T_{\mathrm{KD}})^{\mathbf{STCS}} \tag{4.56}$$

$$\boldsymbol{\theta}_{\mathbf{cs}} = \mathbf{THECS} \cdot (T_{\mathrm{KR}}/T_{\mathrm{KD}})^{\mathbf{STTHECS}} \tag{4.57}$$

$$\boldsymbol{E}_{\mathbf{eff0}} = 10^{-8} \cdot C_{\mathrm{ox}}/\epsilon_{\mathrm{Si}} \tag{4.58}$$

$$\boldsymbol{\eta}_{\boldsymbol{\mu}} = \begin{cases} 1/2 \cdot \mathbf{FETA} & \text{for NMOS} \\ 1/3 \cdot \mathbf{FETA} & \text{for PMOS} \end{cases} \tag{4.59}$$

$$\boldsymbol{\eta}_{\boldsymbol{\mu},\mathbf{ac}} = \begin{cases} 1/2 & \text{for NMOS} \\ 1/3 & \text{for PMOS} \end{cases} \tag{4.60}$$

Series resistance parameters

$$R_{\mathrm{s}} = \mathbf{RS} \cdot (T_{\mathrm{KR}}/T_{\mathrm{KD}})^{\mathbf{STRS}} \tag{4.61}$$

$$\boldsymbol{\theta}_{\mathbf{R}} = 2 \cdot \boldsymbol{\beta} \cdot R_{\mathrm{s}} \tag{4.62}$$

Velocity saturation parameters

$$\boldsymbol{\theta}_{\mathbf{sat}} = \mathbf{THESAT} \cdot (T_{\mathrm{KR}}/T_{\mathrm{KD}})^{\mathbf{STTHESAT}} \tag{4.63}$$

$$\boldsymbol{\theta}_{\mathbf{sat,ac}} = \mathbf{THESATAC} \cdot (T_{\mathrm{KR}}/T_{\mathrm{KD}})^{\mathbf{STTHESAT}} \tag{4.64}$$

Linear-saturation transition parameters

$$\boldsymbol{ar} = \frac{\left(2^{-2/\mathbf{AX}+1} - 2\right)^2}{max\left(4 \cdot \left(2^{-2/\mathbf{AX}+1} - 1\right), 10^{-4}\right)} \tag{4.65}$$

$$\boldsymbol{ar}_{\mathbf{ac}} = \frac{\left(2^{-2/\mathbf{AXAC}+1} - 2\right)^2}{max\left(4 \cdot \left(2^{-2/\mathbf{AXAC}+1} - 1\right), 10^{-4}\right)} \tag{4.66}$$

Gate current parameters

$$\boldsymbol{I}_{\mathbf{GINV}} = \mathbf{IGINV} \cdot \left(T_{\mathrm{KA}}/T_{\mathrm{KR}}\right)^{\mathbf{STIG}} \tag{4.67}$$

$$\boldsymbol{I}_{\mathbf{GOV}} = \mathbf{IGOV} \cdot \left(T_{\mathrm{KA}}/T_{\mathrm{KR}}\right)^{\mathbf{STIG}} \tag{4.68}$$

$$\boldsymbol{I}_{\mathbf{GOVD}} = \mathbf{IGOVD} \cdot \left(T_{\mathrm{KA}}/T_{\mathrm{KR}}\right)^{\mathbf{STIG}} \tag{4.69}$$

$$\boldsymbol{B} = \frac{4}{3} \cdot \frac{\mathbf{TOX}}{\hbar} \cdot \sqrt{2 \cdot q \cdot m_0 \cdot \mathbf{CHIB}} = 6.830909 \cdot 10^9 \cdot \mathbf{TOX} \cdot \sqrt{\mathbf{CHIB}} \tag{4.70}$$

$$\boldsymbol{B}_{\mathbf{ov}} = \boldsymbol{B} \cdot \mathbf{TOXOV}/\mathbf{TOX} \tag{4.71}$$

$$\boldsymbol{B}_{\mathbf{ovd}} = \boldsymbol{B} \cdot \mathbf{TOXOVD}/\mathbf{TOX} \tag{4.72}$$

$$\boldsymbol{GC}_{\mathbf{Q}} = \begin{cases} -0.99 \cdot \dfrac{\mathbf{GC2}}{2 \cdot \mathbf{GC3}} & \text{for } \mathbf{GC3} < 0 \\ \\ 0 & \text{for } \mathbf{GC3} \geq 0 \end{cases} \tag{4.73}$$

$$\boldsymbol{\alpha}_{\mathbf{b}} = \frac{E_{\mathrm{g}}/q + \boldsymbol{\phi}_{\mathbf{B,dc}}}{2} \tag{4.74}$$

$$\boldsymbol{gc}_{\mathbf{2,ov}} = \begin{cases} \mathbf{GC2OV} & \text{for } \mathbf{SWIGATE} = 2 \\ \mathbf{GC2} & \text{else} \end{cases} \tag{4.75}$$

$$\boldsymbol{gc}_{\mathbf{3,ov}} = \begin{cases} \mathbf{GC3OV} & \text{for } \mathbf{SWIGATE} = 2 \\ \mathbf{GC3} & \text{else} \end{cases} \tag{4.76}$$

$$\boldsymbol{GC}_{\mathbf{Q,ov}} = \begin{cases} -0.99 \cdot \dfrac{\boldsymbol{gc}_{\mathbf{2,ov}}}{2 \cdot \boldsymbol{gc}_{\mathbf{3,ov}}} & \text{for } \boldsymbol{gc}_{\mathbf{3,ov}} < 0 \\ \\ 0 & \text{for } \boldsymbol{gc}_{\mathbf{3,ov}} \geq 0 \end{cases} \tag{4.77}$$

Gate-induced drain leakage parameters

$$\boldsymbol{A}_{\mathbf{GIDL}} = \mathbf{AGIDL} \cdot \left(\frac{2 \cdot 10^{-9}}{\mathbf{TOXOV}}\right)^2 \tag{4.78}$$

$$\boldsymbol{A}_{\mathbf{GIDLD}} = \mathbf{AGIDLD} \cdot \left(\frac{2 \cdot 10^{-9}}{\mathbf{TOXOVD}}\right)^2 \tag{4.79}$$

$$\boldsymbol{B}_{\mathbf{GIDL}} = \mathbf{BGIDL} \cdot \mathrm{MAX}\left(\left[1 + \mathbf{STBGIDL} \cdot \Delta T_{\mathrm{A}}\right], 0\right) \cdot \left(\frac{\mathbf{TOXOV}}{2 \cdot 10^{-9}}\right) \tag{4.80}$$

$$\boldsymbol{B}_{\mathbf{GIDLD}} = \mathbf{BGIDLD} \cdot \mathrm{MAX}\left(\left[1 + \mathbf{STBGIDLD} \cdot \Delta T_{\mathrm{A}}\right], 0\right) \cdot \left(\frac{\mathbf{TOXOVD}}{2 \cdot 10^{-9}}\right) \tag{4.81}$$

Inner fringe charge parameters

$$\boldsymbol{V}_{\mathbf{inr,max}} = \begin{cases} \dfrac{3}{4 \cdot \textbf{FCINRACC}} & \text{for } \textbf{FCINRACC} > 10^{-10} \\ 0 & \text{else} \end{cases} \tag{4.82}$$

$$\boldsymbol{a}_{\mathbf{inr}} = \textbf{AXINR}^2 \tag{4.83}$$

Noise parameter

$$\boldsymbol{N_T} = \textbf{FNT} \cdot 4 \cdot k_{\mathrm{B}} \cdot T_{\mathrm{KD}} \tag{4.84}$$

Edge transistor parameters

$$\boldsymbol{V}_{\mathbf{FB,edge}} = \textbf{VFBEDGE} + \textbf{STVFBEDGE} \cdot \Delta T + \textbf{DELVTOEDGE} \tag{4.85}$$

$$\boldsymbol{\beta}_{\mathbf{edge}} = \textbf{FACTUOEDGE} \cdot \textbf{BETNEDGE} \cdot C_{\mathrm{ox}} \cdot (T_{\mathrm{KR}}/T_{\mathrm{KD}})^{\textbf{STBETEDGE}} \tag{4.86}$$

$$\boldsymbol{\phi}^*_{\mathbf{T0,edge}} = \boldsymbol{\phi}_{\mathbf{T}} \cdot \left(1 + \textbf{CTEDGE} \cdot \frac{T_{\mathrm{KR}}}{T_{\mathrm{KD}}}\right) \tag{4.87}$$

$$\boldsymbol{\phi}_{\mathbf{B,edge}} = \mathrm{MAX}\left(\textbf{DPHIBEDGE} + 2 \cdot \boldsymbol{\phi}^*_{\mathbf{T0,edge}} \cdot \ln\left[\textbf{NEFFEDGE}/n_{\mathrm{i}}\right], 0.05\right) \tag{4.88}$$

$$\gamma_{edge} = \sqrt{2 \cdot q \cdot \epsilon_{\mathrm{Si}} \cdot \textbf{NEFFEDGE}}/C_{\mathrm{ox}} \tag{4.89}$$

$$\boldsymbol{G}_{\mathbf{edge}} = \gamma_{edge}/\sqrt{\boldsymbol{\phi}_{\mathbf{T}}} \tag{4.90}$$

$$\boldsymbol{\phi}_{\mathbf{X,edge}} = 0.95 \cdot \boldsymbol{\phi}_{\mathbf{B,edge}} \tag{4.91}$$

$$\boldsymbol{\phi}^*_{\mathbf{X,edge}} = \mathrm{MINA}\left(\frac{1}{2} \cdot \left(\boldsymbol{\phi}_{\mathbf{B,edge}} + \boldsymbol{\phi}_{\mathbf{X,edge}}\right), 0, \left(\boldsymbol{\phi}_{\mathbf{B,edge}} - \boldsymbol{\phi}_{\mathbf{X,edge}}\right)^2\right) \tag{4.92}$$

$$\boldsymbol{N}_{\mathbf{T,edge}} = \textbf{FNTEDGE} \cdot 4 \cdot k_{\mathrm{B}} \cdot T_{\mathrm{KD}} \tag{4.93}$$

Impact-ionization parameter

$$\boldsymbol{a_2} = \textbf{A2} \cdot (T_{\mathrm{KD}}/T_{\mathrm{KR}})^{\textbf{STA2}} \tag{4.94}$$

Self heating parameter

$$\boldsymbol{R}_{\mathbf{TH}} = \textbf{RTH} \cdot \left(\frac{T_{\mathrm{KA}}}{T_{\mathrm{KR}}}\right)^{\textbf{STRTH}} \tag{4.95}$$

Additional internal parameters

$$\boldsymbol{x_1} = 1.25 \tag{4.96}$$

4.2 Current Model

In this section, the current model equations of the PSP-model are given. Use is made of the applied terminal bias values $V_{\rm GS}$, $V_{\rm DS}$ and $V_{\rm SB}$, the local parameters listed in Section 2.5.2 and the internal parameters introduced in Section 4.1. Local parameters are denoted by capital characters in bold font, whereas internal (bias-independent) parameters are denoted by symbols in bold font.

The definitions of the auxiliary functions MINA(.), MAXA(.), $\chi(.)$ and $\sigma_{1,2}(.)$ can be found in Appendix A.

Depending on the value of the parameters **SWNUD** and **SWDELVTAC**, the surface potentials (at source- and drain-side of the channel) and associated computations, i.e., Eq. (4.109) to Eq. (4.216), may be evaluated twice: once for the dc-characteristics and a second time for the ac-characteristics of the model.

As the same way, if the charge model decoupling in saturation is selected, i.e., if **SWQSAT** is set to 1, the surface potential at drain-side of the channel and its associated variables (from Eq. (4.157) to Eq. (4.216)) are calculated twice.

4.2.1 Conditioning of Terminal Voltages

$$V^*_{\rm GB} = V_{\rm GB} - \boldsymbol{V_{\rm FB}} \tag{4.97}$$

$$V_{\rm dsx} = \frac{V^2_{\rm DS}}{\sqrt{{V_{\rm DS}}^2 + 0.01} + 0.1} \tag{4.98}$$

$$\phi_{\rm V,dc} = {\rm MINA}\left(V_{\rm SB},\, V_{\rm SB} + V_{\rm DS},\, \boldsymbol{b_{\phi,\rm dc}}\right) + \boldsymbol{\phi_{\rm X,dc}} \tag{4.99}$$

$$\phi_{\rm V,ac} = {\rm MINA}\left(V_{\rm SB},\, V_{\rm SB} + V_{\rm DS},\, \boldsymbol{b_{\phi,\rm ac}}\right) + \boldsymbol{\phi_{\rm X,ac}} \tag{4.100}$$

$$V^*_{\rm SB,dc} = V_{\rm SB} - {\rm MINA}\left(\phi_{\rm V,dc},\, 0,\, \boldsymbol{a_{\phi,\rm dc}}\right) + \boldsymbol{\phi^*_{\rm X,dc}} \tag{4.101}$$

$$V^*_{\rm SB,ac} = V_{\rm SB} - {\rm MINA}\left(\phi_{\rm V,ac},\, 0,\, \boldsymbol{a_{\phi,\rm ac}}\right) + \boldsymbol{\phi^*_{\rm X,ac}} \tag{4.102}$$

Nonuniform doping effect. Eqs. (4.103)–(4.108) are only evaluated when **SWNUD** $\neq 0$ and **GFACNUD** $\neq 1$:

$$V_{\rm mB} = V^*_{\rm SB} + 0.5 \cdot \left(V_{\rm DS} - V_{\rm dsx}\right) \tag{4.103}$$

$$u_{\rm s} = \sqrt{V_{\rm mB} + \boldsymbol{\phi_{\rm B}}} - \sqrt{\boldsymbol{\phi_{\rm B}}} \tag{4.104}$$

$$p = 2 \cdot \frac{u_{\rm s} - u_{\rm s1}}{u_{\rm s21}} - 1 \tag{4.105}$$

$$u_{\rm s,nud} = u_{\rm s} - 0.25 \cdot (1 - \textbf{GFACNUD}) \cdot u_{\rm s21} \cdot \left\{p + \sqrt{p^2 + [\ln(2)]^2}\right\} \tag{4.106}$$

$$V_{\rm mB,nud} = \left(u_{\rm s,nud} + 2 \cdot \sqrt{\boldsymbol{\phi_{\rm B}}}\right) \cdot u_{\rm s,nud} \tag{4.107}$$

$$V^*_{\rm SB,dc} = V_{\rm mB,nud} - 0.5 \cdot \left(V_{\rm DS} - V_{\rm dsx}\right) \tag{4.108}$$

The surface potential (at source- and drain-side of the channel) and associated computations, i.e., Eqs. (4.109)–(4.216), are evaluated using $V^*_{\rm SB} = V^*_{\rm SB,dc}$, $\boldsymbol{\phi_{\rm B}} = \boldsymbol{\phi_{\rm B,dc}}$ and $\boldsymbol{G_0} = \boldsymbol{G_{0,\rm dc}}$. However, if **SWNUD** $= 1$ or **SWDELVTAC** $= 1$, these equations are evaluated a second time using $V^*_{\rm SB} = V^*_{\rm SB,ac}$, $\boldsymbol{\phi_{\rm B}} = \boldsymbol{\phi_{\rm B,ac}}$, and $\boldsymbol{G_0} = \boldsymbol{G_{0,\rm ac}}$.

$$V_{\mathrm{DB}}^{*} = V_{\mathrm{DS}} + V_{\mathrm{SB}}^{*} \tag{4.109}$$

$$V_{\mathrm{sbx}} = V_{\mathrm{SB}}^{*} + \frac{V_{\mathrm{DS}} - V_{\mathrm{dsx}}}{2} \tag{4.110}$$

4.2.2 Interface States Including Bias Dependences

$$x_{\mathrm{g,ct}} = \frac{V_{\mathrm{GB}}^{*}}{\boldsymbol{\phi_{\mathrm{T}}}} \tag{4.111}$$

$$x_{\mathrm{b,ct}} = \frac{\boldsymbol{\phi_{\mathrm{B}}}}{\boldsymbol{\phi_{\mathrm{T}}}} \tag{4.112}$$

$$x_{\mathrm{sb,ct}}^{*} = \frac{V_{\mathrm{sbx}}}{\boldsymbol{\phi_{\mathrm{T}}}} \tag{4.113}$$

$$x_{\mathrm{wi,ct}} = \frac{x_{\mathrm{g,ct}} - x_{\mathrm{b,ct}} - G_0 \cdot \sqrt{x_{\mathrm{b,ct}}}}{1 + G_0 / \left(2 \cdot \sqrt{x_{\mathrm{b,ct}}}\right)} + \frac{x_{\mathrm{b,ct}}}{2} - (1 + \mathbf{CTB}) \cdot x_{\mathrm{sb,ct}}^{*} \tag{4.114}$$

$$x_{\mathrm{ct,max}} = \frac{x_{\mathrm{b,ct}}}{2} + 2 \tag{4.115}$$

$$x_{\mathrm{n,ct}} = x_{\mathrm{b,ct}} + x_{\mathrm{sb,ct}}^{*} \tag{4.116}$$

$$x_{\mathrm{mi,ct}} = 2 \cdot \left(x_{\mathrm{g,ct}} - x_{\mathrm{n,ct}} - G_0 \cdot \sqrt{x_{\mathrm{n,ct}}} - 2 \cdot \ln\left(\frac{x_{\mathrm{b,ct}}}{G_0} + \sqrt{x_{\mathrm{b,ct}}} \right) \right) + x_{\mathrm{ct,max}} \tag{4.117}$$

$$x_{\mathrm{sub,ct}} = \mathrm{MINA}\left(\mathrm{MAXA}\left(x_{\mathrm{wi,ct}}, x_{\mathrm{mi,ct}}, 20 \right), 2 \cdot \left(x_{\mathrm{g,ct}} - x_{\mathrm{sb,ct}}^{*} \right), 20 \right) \tag{4.118}$$

$$x_{\mathrm{ct}} = \mathrm{MAXA}\left(\mathrm{MINA}\left(x_{\mathrm{sub,ct}}, x_{\mathrm{ct,max}}, 5 \right), -x_{\mathrm{ct,max}}, 20 \right) \tag{4.119}$$

$$\phi_{\mathrm{T,ct}} = \boldsymbol{\phi_{\mathrm{T}}} \cdot \left(1 + \boldsymbol{C_{\mathrm{T}}} \cdot \exp\left(\boldsymbol{C_{\mathrm{TG}}} \cdot \left(\frac{x_{\mathrm{ct}}}{x_{\mathrm{ct,max}}} + 1 \right) \right) \right) \tag{4.120}$$

4.2.3 Short Channel effects

Subthreshold slope degradation induced by short channel effects:

$$\Delta\phi_{\mathrm{T}}^{*} = \mathbf{PSCE} \cdot (1 + \mathbf{PSCED} \cdot V_{\mathrm{dsx}}) \cdot (1 + \mathbf{PSCEB} \cdot V_{\mathrm{sbx}}) \tag{4.121}$$

$$\phi_{\mathrm{T}}^{*} = \phi_{\mathrm{T,ct}} \cdot (1 + \Delta\phi_{\mathrm{T}}^{*}) \tag{4.122}$$

$$G = G_0 \cdot (\phi_{\mathrm{T}} / \phi_{\mathrm{T}}^{*}) \tag{4.123}$$

Drain-induced barrier lowering:

$$x_{\mathrm{g}} = V_{\mathrm{GB}}^{*} / \phi_{\mathrm{T}}^{*} \tag{4.124}$$

$$V_{\mathrm{ds}}^{*} = \frac{2 \cdot V_{\mathrm{dsx}}}{1 + \sqrt{1 + \mathbf{CFD} \cdot V_{\mathrm{dsx}}}} \tag{4.125}$$

$$\Delta\phi_{\mathrm{B}} = \mathbf{CF} \cdot V_{\mathrm{dsx}}^{*} \cdot (1 + \mathbf{CFB} \cdot V_{\mathrm{sbx}}) \tag{4.126}$$

$$x_{\mathrm{n0s}} = \frac{\boldsymbol{\phi}_{\mathbf{B}} + V_{\mathrm{SB}}^{*}}{\phi_{\mathrm{T}}^{*}} \tag{4.127}$$

$$x_{\mathrm{ns}}^{*} = x_{\mathrm{n0s}} - \frac{\Delta\phi_{\mathrm{B}}}{\phi_{\mathrm{T}}^{*}} \tag{4.128}$$

$$n_{\mathrm{scr}} = 1 + \frac{G}{2 \cdot \sqrt{x_{\mathrm{ns}}^{*}}} \tag{4.129}$$

$$x_{\mathrm{th,scr}} = x_{\mathrm{ns}}^{*} + G \cdot \sqrt{x_{\mathrm{ns}}^{*}} - n_{\mathrm{scr}} \cdot \ln\left(n_{\mathrm{scr}} - 1\right) \tag{4.130}$$

$$x_{\mathrm{gt,scr}} = \frac{x_{\mathrm{g}} - x_{\mathrm{th,scr}}}{n_{\mathrm{scr}}} \tag{4.131}$$

$$\text{if } x_{\mathrm{gt,scr}} > -20 \begin{cases} x_{\mathrm{gt,scr,0}} = n_{\mathrm{scr}} \cdot x_{\mathrm{gt,scr}} - 1 \\ q_{\mathrm{i,scr,0,si}} = x_{\mathrm{gt,scr}} - \ln\left(\left(x_{\mathrm{gt,scr,0}} + \sqrt{{x_{\mathrm{gt,scr,0}}}^{2} + 10}\right)/2\right) \\ q_{\mathrm{i,scr,0}} = \left(q_{\mathrm{i,scr,0,si}} + \sqrt{{q_{\mathrm{i,scr,0,si}}}^{2} + 2}\right)/2 \\ \delta_{\mathrm{scr,0}} = \exp\left(x_{\mathrm{gt,scr}} - q_{\mathrm{i,scr,0}}\right)/n_{\mathrm{scr}} \\ q_{\mathrm{i,scr}} = n_{\mathrm{scr}} \cdot \left(q_{\mathrm{i,scr,0}} - \left(\sqrt{1 + \delta_{\mathrm{scr,0}} \cdot \left(2 \cdot \left(q_{\mathrm{i,scr,0}} + 1\right) - \delta_{\mathrm{scr,0}}\right)} - 1\right)/\delta_{\mathrm{scr,0}} + 1\right) \\ q_{\mathrm{b,scr}} = G^{2}/2 \cdot \left(\sqrt{1 + 4 \cdot \left(x_{\mathrm{g}} - q_{\mathrm{i,scr}}\right)/G^{2}} - 1\right) \\ f_{\mathrm{scr}} = q_{\mathrm{b,scr}}/\left(q_{\mathrm{b,scr}} + q_{\mathrm{i,scr}}\right) \end{cases} \tag{4.132}$$

$$\text{else} \left\{ \; f_{\mathrm{scr}} = 1 \right. \tag{4.133}$$

$$x_{\mathrm{ns}} = x_{\mathrm{n0s}} - f_{\mathrm{scr}} \cdot \frac{\Delta\phi_{\mathrm{B}}}{\phi_{\mathrm{T}}^{*}} \tag{4.134}$$

4.2.4 Surface Potential at Source Side and Related Variables

$$\xi = 1 + G/\sqrt{2} \tag{4.135}$$

$$x_{\mathrm{mrg}} = 10^{-5} \cdot \xi \tag{4.136}$$

$$\Delta_{\mathrm{ns}} = \exp\left(-x_{\mathrm{ns}}\right) \tag{4.137}$$

$$\text{if } x_{\mathrm{g}} < -x_{\mathrm{mrg}} \begin{cases} y_{\mathrm{g}} = -x_{\mathrm{g}} \\ z = 1.25 \cdot y_{\mathrm{g}} / \xi \\ \eta = \left[z + 10 - \sqrt{(z-6)^2 + 64} \right] / 2 \\ a = \left(y_{\mathrm{g}} - \eta \right)^2 + G^2 \cdot (\eta + 1) \\ c = 2 \cdot (y_{\mathrm{g}} - \eta) - G^2 \\ \tau = -\eta + \ln \left(a / G^2 \right) \\ y_0 = \sigma_1(a,\, c,\, \tau,\, \eta) \\ \Delta_0 = \exp\left(y_0 \right) \\ p = 2 \cdot (y_{\mathrm{g}} - y_0) + G^2 \cdot \left[\Delta_0 - 1 + \Delta_{\mathrm{ns}} \cdot (1 - \chi'(y_0) - 1/\Delta_0) \right] \\ q = \left(y_{\mathrm{g}} - y_0 \right)^2 + G^2 \cdot \left[y_0 - \Delta_0 + 1 + \Delta_{\mathrm{ns}} \cdot (1 + \chi(y_0) - 1/\Delta_0 - 2 \cdot y_0) \right] \\ x_{\mathrm{s}} = -y_0 - \dfrac{2 \cdot q}{p + \sqrt{p^2 - 2 \cdot q \cdot \{2 - G^2 \cdot [\Delta_0 + \Delta_{\mathrm{ns}} \cdot (1/\Delta_0 - \chi''(y_0))]\}}} \end{cases} \tag{4.138}$$

$$\text{if } |x_{\mathrm{g}}| \leq x_{\mathrm{mrg}} \left\{ \; x_{\mathrm{s}} = \frac{x_{\mathrm{g}}}{\xi} \cdot \left[1 + G \cdot x_{\mathrm{g}} \cdot \frac{1 - \Delta_{\mathrm{ns}}}{\xi^2 \cdot 6 \cdot \sqrt{2}} \right] \right. \tag{4.139}$$

$$\text{if } x_{\mathrm{g}} > x_{\mathrm{mrg}} \begin{cases} \hat{x}_{\mathrm{g1}} = \boldsymbol{x_1} + G \cdot \sqrt{\exp(-\boldsymbol{x_1}) + \boldsymbol{x_1} - 1} \\ \bar{x} = \dfrac{x_{\mathrm{g}}}{\xi} \cdot \left[1 + x_{\mathrm{g}} \cdot (\xi \cdot \boldsymbol{x_1} - \hat{x}_{\mathrm{g1}}) / \hat{x}_{\mathrm{g1}}^2 \right] \\ x_0 = x_{\mathrm{g}} + G^2/2 - G \cdot \sqrt{x_{\mathrm{g}} + G^2/4 - 1 + \exp(-\bar{x})} \\ b_{\mathrm{x}} = x_{\mathrm{ns}} + 3 \\ \eta = \mathrm{MINA}(x_0,\, b_{\mathrm{x}},\, 5) - \left(b_{\mathrm{x}} - \sqrt{b_{\mathrm{x}}^2 + 5} \right) / 2 \\ a = (x_{\mathrm{g}} - \eta)^2 - G^2 \cdot \left[\exp(-\eta) + \eta - 1 - \Delta_{\mathrm{ns}} \cdot (\eta + 1 + \chi(\eta)) \right] \\ b = 1 - G^2/2 \cdot \left[\exp(-\eta) - \Delta_{\mathrm{ns}} \cdot \chi''(\eta) \right] \\ c = 2 \cdot (x_{\mathrm{g}} - \eta) + G^2 \cdot \left[1 - \exp(-\eta) - \Delta_{\mathrm{ns}} \cdot (1 + \chi'(\eta)) \right] \\ \tau = x_{\mathrm{ns}} - \eta + \ln \left(a / G^2 \right) \\ y_0 = \sigma_2(a,\, b,\, c,\, \tau,\, \eta) \\ \Delta_0 = \exp\left(y_0 \right) \\ p = 2 \cdot (x_{\mathrm{g}} - y_0) + G^2 \cdot \left[1 - 1/\Delta_0 + \Delta_{\mathrm{ns}} \cdot (\Delta_0 - 1 - \chi'(y_0)) \right] \\ q = \left(x_{\mathrm{g}} - y_0 \right)^2 - G^2 \cdot \left[y_0 + 1/\Delta_0 - 1 + \Delta_{\mathrm{ns}} \cdot (\Delta_0 - y_0 - 1 - \chi(y_0)) \right] \\ x_{\mathrm{s}} = y_0 + \dfrac{2 \cdot q}{p + \sqrt{p^2 - 2 \cdot q \cdot \{2 - G^2 \cdot [1/\Delta_0 + \Delta_{\mathrm{ns}} \cdot (\Delta_0 - \chi''(y_0))]\}}} \end{cases} \tag{4.140}$$

Eqs. (4.141)-(4.143) are only calculated for $x_{\mathrm{g}} > 0$.

$$E_{\mathrm{s}} = \exp\left(-x_{\mathrm{s}} \right) \tag{4.141}$$

$$D_{\mathrm{s}} = [1/E_{\mathrm{s}} - x_{\mathrm{s}} - 1 - \chi(x_{\mathrm{s}})] \cdot \Delta_{\mathrm{ns}} \tag{4.142}$$

$$P_{\mathrm{s}} = x_{\mathrm{s}} - 1 + E_{\mathrm{s}} \tag{4.143}$$

$$\alpha_{\mathrm{s}} = 1 + \frac{G \cdot (1 - E_{\mathrm{s}})}{2 \cdot \sqrt{P_{\mathrm{s}}}} \tag{4.144}$$

$$x_{\mathrm{gs}} = \begin{cases} x_{\mathrm{g}} - x_{\mathrm{s}} & \text{for } x_{\mathrm{g}} \leq 0 \\ G \cdot \sqrt{D_{\mathrm{s}} + P_{\mathrm{s}}} & \text{for } x_{\mathrm{g}} > 0 \end{cases} \tag{4.145}$$

$$\psi_{\mathrm{ss}} = \phi_{\mathrm{T}}^{*} \cdot x_{\mathrm{s}} \tag{4.146}$$

4.2.5 Drain Saturation Voltage

Eqs. (4.147)-(4.175) are only calculated for $x_{\mathrm{g}} > 0$.

$$q_{\mathrm{is}} = \frac{G^2 \cdot \phi_{\mathrm{T}}^{*} \cdot D_{\mathrm{s}}}{x_{\mathrm{gs}} + G \cdot \sqrt{P_{\mathrm{s}}}} \tag{4.147}$$

$$q_{\mathrm{bs}} = \phi_{\mathrm{T}}^{*} \cdot G \cdot \sqrt{P_{\mathrm{s}}} \tag{4.148}$$

$$\rho_{\mathrm{b}} = \begin{cases} 1 + \textbf{RSB} \cdot V_{\mathrm{sbx}} & \text{for } \textbf{RSB} \geq 0 \\ \dfrac{1}{1 - \textbf{RSB} \cdot V_{\mathrm{sbx}}} & \text{for } \textbf{RSB} < 0 \end{cases} \tag{4.149}$$

$$\rho_{\mathrm{g,s}} = \begin{cases} \dfrac{1}{1 + \textbf{RSG} \cdot q_{\mathrm{is}}} & \text{for } \textbf{RSG} \geq 0 \\ 1 - \textbf{RSG} \cdot q_{\mathrm{is}} & \text{for } \textbf{RSG} < 0 \end{cases} \tag{4.150}$$

$$\rho_{\mathrm{s}} = \boldsymbol{\theta_{\mathrm{R}}} \cdot \rho_{\mathrm{b}} \cdot \rho_{\mathrm{g,s}} \cdot q_{\mathrm{is}} \tag{4.151}$$

$$\mu_{\mathrm{x}} = \frac{1 + \boldsymbol{X_{\mathrm{cor}}} \cdot V_{\mathrm{sbx}}}{1 + 0.2 \cdot \boldsymbol{X_{\mathrm{cor}}} \cdot V_{\mathrm{sbx}}} \tag{4.152}$$

$$E_{\mathrm{eff,s}} = \boldsymbol{E_{\mathrm{eff0}}} \cdot (q_{\mathrm{bs}} + \boldsymbol{\eta_{\mu}} \cdot q_{\mathrm{is}}) \tag{4.153}$$

$$G_{\mathrm{mob,s}} = \frac{1 + (\boldsymbol{\mu_{\mathrm{E}}} \cdot E_{\mathrm{eff,s}})^{\boldsymbol{\theta_{\mu}}} + \boldsymbol{C_{\mathrm{S}}} \cdot \left(\dfrac{q_{\mathrm{bs}}}{q_{\mathrm{is}} + q_{\mathrm{bs}}}\right)^{\boldsymbol{\theta_{\mathrm{cs}}}} + \rho_{\mathrm{s}}}{\mu_{\mathrm{x}}} \tag{4.154}$$

$$\xi_{\mathrm{tb}} = \begin{cases} 1 + \textbf{THESATB} \cdot V_{\mathrm{sbx}} & \text{for } \textbf{THESATB} \geq 0 \\ \dfrac{1}{1 - \textbf{THESATB} \cdot V_{\mathrm{sbx}}} & \text{for } \textbf{THESATB} < 0 \end{cases} \tag{4.155}$$

$$w_{\mathrm{sat,s}} = \frac{q_{\mathrm{is}} \cdot \xi_{\mathrm{tb}}}{\textbf{THESATT} + q_{\mathrm{is}} \cdot \xi_{\mathrm{tb}}} \tag{4.156}$$

$$\theta^*_{\mathrm{sat,s}} = \begin{cases} \dfrac{\boldsymbol{\theta_{\mathrm{sat}}}}{G_{\mathrm{mob,s}}} \cdot (1 + \mathbf{THESATG} \cdot w_{\mathrm{sat,s}}) & \text{for } \mathbf{THESATG} \geq 0 \\[2ex] \dfrac{\boldsymbol{\theta_{\mathrm{sat}}}}{G_{\mathrm{mob,s}}} \cdot \dfrac{1}{1 - \mathbf{THESATG} \cdot w_{\mathrm{sat,s}}} & \text{for } \mathbf{THESATG} < 0 \end{cases} \tag{4.157}$$

$$a_{\mathrm{sat}} = x_{\mathrm{gs}} + G^2/2 \tag{4.158}$$

$$x_{\infty,0} = \left(1 - \sqrt{1 - \frac{G^2}{E_{\mathrm{s}} \cdot a_{\mathrm{sat}}^2}}\right) \cdot a_{\mathrm{sat}} \tag{4.159}$$

$$q_{\mathrm{i,sat}} = q_{\mathrm{is}} - \alpha_{\mathrm{s}} \cdot 0.475 \cdot \phi^*_{\mathrm{T}} \cdot x_{\infty,0} \tag{4.160}$$

$$q_{\mathrm{b,sat}} = \phi^*_{\mathrm{T}} \cdot (x_{\mathrm{gs}} - 0.475 \cdot x_{\infty,0}) - q_{\mathrm{i,sat}} \tag{4.161}$$

$$\alpha_{\mathrm{sat}} = 1 + \frac{G^2 \cdot \phi^*_{\mathrm{T}}}{2 \cdot q_{\mathrm{b,sat}}} \tag{4.162}$$

$$G_{\mathrm{mob,mu,sat}} = \left(\boldsymbol{\mu_{\mathrm{E}}} \cdot \boldsymbol{E_{\mathrm{eff0}}} \cdot (q_{\mathrm{b,sat}} + \boldsymbol{\eta_{\mu}} \cdot q_{\mathrm{i,sat}})\right)^{\boldsymbol{\theta_{\mu}}} \tag{4.163}$$

$$\delta G_{\mathrm{mob,mu,sat}} = \boldsymbol{\theta_{\mu}} \cdot \frac{\alpha_{\mathrm{sat}} \cdot (1 - \boldsymbol{\eta_{\mu}}) - 1}{q_{\mathrm{b,sat}} + \boldsymbol{\eta_{\mu}} \cdot q_{\mathrm{i,sat}}} \cdot G_{\mathrm{mob,mu,sat}} \tag{4.164}$$

$$G_{\mathrm{mob,cs,sat}} = \boldsymbol{C_{\mathrm{S}}} \cdot \left(1 + \frac{q_{\mathrm{i,sat}}}{q_{\mathrm{b,sat}}}\right)^{-\boldsymbol{\theta_{\mathrm{cs}}}} \tag{4.165}$$

$$\delta G_{\mathrm{mob,cs,sat}} = \boldsymbol{\theta_{\mathrm{cs}}} \cdot \frac{\alpha_{\mathrm{sat}} - 1 + 1/(q_{\mathrm{i,sat}}/q_{\mathrm{b,sat}} + 1)}{q_{\mathrm{b,sat}}} \cdot G_{\mathrm{mob,cs,sat}} \tag{4.166}$$

$$\rho_{\mathrm{sat}} = \boldsymbol{\theta_{\mathrm{R}}} \cdot \rho_{\mathrm{b}} \cdot \rho_{\mathrm{g,s}} \cdot q_{\mathrm{i,sat}} \tag{4.167}$$

$$\delta\rho_{\mathrm{sat}} = -\frac{\alpha_{\mathrm{sat}}}{q_{\mathrm{i,sat}}} \cdot \rho_{\mathrm{sat}} \tag{4.168}$$

$$\delta G_{\mathrm{mob}} = -0.475 \cdot \phi^*_{\mathrm{T}} \cdot x_{\infty,0} \cdot \frac{\delta G_{\mathrm{mob,mu,sat}} + \delta G_{\mathrm{mob,cs,sat}} + \delta\rho_{\mathrm{sat}}}{1 + G_{\mathrm{mob,mu,sat}} + G_{\mathrm{mob,cs,sat}} + \rho_{\mathrm{sat}}} \tag{4.169}$$

$$x_{\infty} = \frac{1 + \delta G_{\mathrm{mob}}}{1 + \delta G_{\mathrm{mob}}/2} \cdot x_{\infty,0} \tag{4.170}$$

$$y_{\mathrm{sat}} = \begin{cases} \phi^*_{\mathrm{T}} \cdot \theta^*_{\mathrm{sat,s}} \cdot x_{\infty}/\sqrt{2} & \text{for NMOS} \\[2ex] \dfrac{\phi^*_{\mathrm{T}} \cdot \theta^*_{\mathrm{sat,s}} \cdot x_{\infty}/\sqrt{2}}{\sqrt{1 + \phi^*_{\mathrm{T}} \cdot \theta^*_{\mathrm{sat,s}} \cdot x_{\infty}/\sqrt{2}}} & \text{for PMOS} \end{cases} \tag{4.171}$$

$$z_{\mathrm{a}} = \frac{2}{1 + \sqrt{1 + 4 \cdot y_{\mathrm{sat}}}} \tag{4.172}$$

$$x_{\mathrm{sat}} = 0.99 \cdot x_{\infty} \cdot z_{\mathrm{a}} \cdot \left[1 + 0.86 \cdot z_{\mathrm{a}} \cdot y_{\mathrm{sat}} \cdot \frac{1 - z_{\mathrm{a}}^2 \cdot y_{\mathrm{sat}}}{1 + 4 \cdot z_{\mathrm{a}}^3 \cdot y_{\mathrm{sat}}^2}\right] \tag{4.173}$$

$$V_{\mathrm{dsat}} = \phi^*_{\mathrm{T}} \cdot \left(x_{\mathrm{sat}} - \ln\left[1 + x_{\mathrm{sat}} \cdot \frac{x_{\mathrm{sat}} - 2 \cdot a_{\mathrm{sat}}}{G^2 \cdot D_{\mathrm{s}}}\right]\right) \tag{4.174}$$

4.2.6 Effective Drain Voltage

$$V_{\mathrm{dse}} = \frac{2 \cdot \sqrt{1+\boldsymbol{ar}} \cdot V_{\mathrm{DS}}}{\sqrt{\left(\sqrt{1+\boldsymbol{ar}} \cdot \frac{V_{\mathrm{DS}}}{V_{\mathrm{dsat}}} - 1\right)^2 + \boldsymbol{ar}} + \sqrt{\left(\sqrt{1+\boldsymbol{ar}} \cdot \frac{V_{\mathrm{DS}}}{V_{\mathrm{dsat}}} + 1\right)^2 + \boldsymbol{ar}}} \tag{4.175}$$

If **SWQSAT** $= 1$, $\boldsymbol{\theta_{\mathrm{sat}}}$ is replaced by $\boldsymbol{\theta_{\mathrm{sat,ac}}}$ into Eq. (4.157) and $\boldsymbol{ar}$ is replaced by $\boldsymbol{ar_{\mathrm{ac}}}$ into Eq. (4.175) during the second calculation for the ac-characteristics of the model (from Eq. (4.157) to Eq. (4.216)) .

4.2.7 Surface Potential at Drain Side and Related Variables

Eqs. (4.176)-(4.187) are only calculated for $x_{\mathrm{g}} > 0$.

$$x_{\mathrm{nd}} = \frac{\boldsymbol{\phi_{\mathrm{B}}} + V_{\mathrm{SB}}^{*} + V_{\mathrm{dse}}}{\phi_{\mathrm{T}}^{*}} \tag{4.176}$$

$$k_{\mathrm{ds}} = \exp\left(-V_{\mathrm{dse}}/\phi_{\mathrm{T}}^{*}\right) \tag{4.177}$$

$$\Delta_{\mathrm{nd}} = \Delta_{\mathrm{ns}} \cdot k_{\mathrm{ds}} \tag{4.178}$$

$$\text{if } x_{\mathrm{g}} \le x_{\mathrm{mrg}} \left\{ \; x_{\mathrm{d}} = \frac{x_{\mathrm{g}}}{\xi} \cdot \left[1 + G \cdot x_{\mathrm{g}} \cdot \frac{1-\Delta_{\mathrm{nd}}}{\xi^2 \cdot 6 \cdot \sqrt{2}}\right] \right. \tag{4.179}$$

$$\text{if } x_{\mathrm{g}} > x_{\mathrm{mrg}} \begin{cases} b_{\mathrm{x}} = x_{\mathrm{nd}} + 3 \\ \eta = \mathrm{MINA}(x_0,\, b_{\mathrm{x}},\, 5) - \left(b_{\mathrm{x}} - \sqrt{b_{\mathrm{x}}^2 + 5}\right)/2 \\ a = (x_{\mathrm{g}} - \eta)^2 - G^2 \cdot [\exp(-\eta) + \eta - 1 - \Delta_{\mathrm{nd}} \cdot (\eta + 1 + \chi(\eta))] \\ b = 1 - G^2/2 \cdot [\exp(-\eta) - \Delta_{\mathrm{nd}} \cdot \chi''(\eta)] \\ c = 2 \cdot (x_{\mathrm{g}} - \eta) + G^2 \cdot [1 - \exp(-\eta) - \Delta_{\mathrm{nd}} \cdot (1 + \chi'(\eta))] \\ \tau = x_{\mathrm{nd}} - \eta + \ln\left(a/G^2\right) \\ y_0 = \sigma_2(a,\, b,\, c,\, \tau,\, \eta) \\ \Delta_0 = \exp\left(y_0\right) \\ p = 2 \cdot (x_{\mathrm{g}} - y_0) + G^2 \cdot [1 - 1/\Delta_0 + \Delta_{\mathrm{nd}} \cdot (\Delta_0 - 1 - \chi'(y_0))] \\ q = (x_{\mathrm{g}} - y_0)^2 - G^2 \cdot [y_0 + 1/\Delta_0 - 1 + \Delta_{\mathrm{nd}} \cdot (\Delta_0 - y_0 - 1 - \chi(y_0))] \\ x_{\mathrm{d}} = y_0 + \dfrac{2 \cdot q}{p + \sqrt{p^2 - 2 \cdot q \cdot \{2 - G^2 \cdot [1/\Delta_0 + \Delta_{\mathrm{nd}} \cdot (\Delta_0 - \chi''(y_0))]\}}} \end{cases} \tag{4.180}$$

$$x_{\mathrm{ds}} = x_{\mathrm{d}} - x_{\mathrm{s}} \tag{4.181}$$

$$\text{if } x_{\mathrm{ds}} < 10^{-10} \begin{cases} p = 2 \cdot x_{\mathrm{gs}} + G^2 \cdot [1 - E_{\mathrm{s}} + \Delta_{\mathrm{nd}} \cdot (1/E_{\mathrm{s}} - 1 - \chi'(x_{\mathrm{s}}))] \\ q = G^2 \cdot (1 - k_{\mathrm{ds}}) \cdot D_{\mathrm{s}} \\ \xi = 1 - G^2/2 \cdot [E_{\mathrm{s}} + \Delta_{\mathrm{nd}}\,(1/E_{\mathrm{s}} - \chi''(x_{\mathrm{s}}))] \\ x_{m}athrmds = \dfrac{2 \cdot q}{p + \sqrt{p^2 - 4 \cdot \xi \cdot q}} \\ x_{\mathrm{d}} = x_{\mathrm{s}} + x_{\mathrm{ds}} \end{cases} \tag{4.182}$$

$$E_{\rm d} = \exp\left(-x_{\rm d}\right) \tag{4.183}$$

$$P_{\rm d} = x_{\rm d} - 1 + E_{\rm d} \tag{4.184}$$

$$q_{\rm bd} = \phi_{\rm T}^* \cdot G \cdot \sqrt{P_{\rm d}} \tag{4.185}$$

$$D_{\rm d} = \left(1/E_{\rm d} - x_{\rm d} - 1 - \chi(x_{\rm d})\right) \cdot \Delta_{\rm nd} \tag{4.186}$$

$$\Delta\psi = \phi_{\rm T}^* \cdot x_{\rm ds} \tag{4.187}$$

$$\psi_{\rm sd} = \phi_{\rm T}^* \cdot x_{\rm d} \tag{4.188}$$

4.2.8 Mid-Point Surface Potential and Related Variables

$$\text{if } x_{\rm g} > 0 \begin{cases} x_{\rm m} = \left(x_{\rm s} + x_{\rm d}\right)/2 \\ E_{\rm m} = \sqrt{E_{\rm s} \cdot E_{\rm d}} \\ \bar{D} = \left(D_{\rm s} + D_{\rm d}\right)/2 \\ D_{\rm m} = \bar{D} + x_{\rm ds}^2/8 \cdot \left(E_{\rm m} - 2/G^2\right) \\ P_{\rm m} = x_{\rm m} - 1 + E_{\rm m} \\ x_{\rm gm} = G \cdot \ sqrt D_{\rm m} + P_{\rm m} \end{cases} \tag{4.189}$$

$$\text{if } x_{\rm g} \le 0 \begin{cases} x_{\rm m} = x_{\rm s} \\ x_{\rm gm} = x_{\rm g} - x_{\rm s} \end{cases} \tag{4.190}$$

4.2.9 Polysilicon Depletion

Eqs. (4.191)-(4.205) are only calculated for $\boldsymbol{k_{\rm P}} > 0$ and $x_{\rm g} > 0$ (otherwise $\eta_{\rm p} = 1$):

$$x_{\rm m}^{(0)} = x_{\rm m}, \qquad x_{\rm ds}^{(0)} = x_{\rm ds}, \qquad D_{\rm m}^{(0)} = D_{\rm m}, \qquad E_{\rm m}^{(0)} = E_{\rm m}, \tag{4.191}$$

$$d_0 = 1 - E_{\rm m}^{(0)} + 2 \cdot x_{\rm gm}/G^2 \tag{4.192}$$

$$\eta_{\rm p} = 1/\sqrt{1 + \boldsymbol{k_{\rm P}} \cdot x_{\rm gm}} \tag{4.193}$$

$$x_{\rm pm} = \boldsymbol{k_{\rm P}} \cdot \left[\frac{\eta_{\rm p} \cdot x_{\rm gm}}{1 + \eta_{\rm p}}\right]^2 \cdot \frac{D_{\rm m}^{(0)}}{D_{\rm m}^{(0)} + P_{\rm m}} \tag{4.194}$$

$$p = 2 \cdot \left(x_{\rm gm} - x_{\rm pm}\right) + G^2 \cdot \left(1 - E_{\rm m}^{(0)} + D_{\rm m}^{(0)}\right) \tag{4.195}$$

$$q = x_{\rm pm} \cdot \left(x_{\rm pm} - 2 \cdot x_{\rm gm}\right) \tag{4.196}$$

$$\xi_{\rm p} = 1 - G^2/2 \cdot \left(E_{\rm m}^{(0)} + D_{\rm m}^{(0)}\right) \tag{4.197}$$

$$u_{\rm p} = \frac{p \cdot q}{p^2 - \xi_{\rm p} \cdot q} \tag{4.198}$$

$$x_{\mathrm{m}} = x_{\mathrm{m}}^{(0)} + u_{\mathrm{p}} \tag{4.199}$$

$$E_{\mathrm{m}} = E_{\mathrm{m}}^{(0)} \cdot \exp\left(-u_{\mathrm{p}}\right) \tag{4.200}$$

$$D_{\mathrm{m}} = D_{\mathrm{m}}^{(0)} \cdot \exp\left(u_{\mathrm{p}}\right) \tag{4.201}$$

$$P_{\mathrm{m}} = x_{\mathrm{m}} - 1 + E_{\mathrm{m}} \tag{4.202}$$

$$x_{\mathrm{gm}} = G \cdot \sqrt{D_{\mathrm{m}} + P_{\mathrm{m}}} \tag{4.203}$$

$$x_{\mathrm{ds}} = x_{\mathrm{ds}}^{(0)} \cdot \frac{\exp\left(u_{\mathrm{p}}\right) \cdot \left[\bar{D} + d_0\right]}{1 - E_{\mathrm{m}} + 2 \cdot x_{\mathrm{gm}} \cdot \eta_{\mathrm{p}} / G^2 + \exp\left(u_{\mathrm{p}}\right) \cdot \bar{D}} \tag{4.204}$$

$$\Delta\psi = \phi_{\mathrm{T}}^{*} \cdot x_{\mathrm{ds}} \tag{4.205}$$

4.2.10 Potential Mid-Point Inversion Charge and Related Variables

Eqs. (4.206)-(4.214) are only calculated for $x_{\mathrm{g}} > 0$.

$$q_{\mathrm{im}} = \frac{G^2 \cdot \phi_{\mathrm{T}}^{*} \cdot D_{\mathrm{m}}}{x_{\mathrm{gm}} + G \cdot \sqrt{P_{\mathrm{m}}}} \tag{4.206}$$

$$\alpha_{\mathrm{m}} = \eta_{\mathrm{p}} + \frac{G \cdot \left(1 - E_{\mathrm{m}}\right)}{2 \cdot \sqrt{P_{\mathrm{m}}}} \tag{4.207}$$

$$q_{\mathrm{im}}^{*} = q_{\mathrm{im}} + \phi_{\mathrm{T}}^{*} \cdot \alpha_{\mathrm{m}} \tag{4.208}$$

$$q_{\mathrm{bm}} = \phi_{\mathrm{T}}^{*} \cdot G \cdot \sqrt{P_{\mathrm{m}}} \tag{4.209}$$

Series resistance:

$$\rho_{\mathrm{g}} = \begin{cases} \dfrac{1}{1 + \textbf{RSG} \cdot q_{\mathrm{im}}} & \text{for } \textbf{RSG} \geq 0 \\[2ex] 1 - \textbf{RSG} \cdot q_{\mathrm{im}} & \text{for } \textbf{RSG} < 0 \end{cases} \tag{4.210}$$

$$\rho_{\mathrm{s}} = \boldsymbol{\theta}_{\mathbf{R}} \cdot \rho_{\mathrm{b}} \cdot \rho_{\mathrm{g}} \cdot q_{\mathrm{im}} \tag{4.211}$$

Mobility reduction:

$$E_{\mathrm{eff}} = \boldsymbol{E}_{\mathbf{eff0}} \cdot \left(q_{\mathrm{bm}} + \boldsymbol{\eta}_{\boldsymbol{\mu}} \cdot q_{\mathrm{im}}\right) \tag{4.212}$$

$$q_{\mathrm{eff1}} = q_{\mathrm{bm}} + \boldsymbol{\eta}_{\boldsymbol{\mu}}\boldsymbol{,}\, \boldsymbol{ac} \cdot q_{\mathrm{im}} \tag{4.213}$$

$$G_{\mathrm{mob}} = \frac{1 + \left(\boldsymbol{\mu}_{\mathbf{E}} \cdot E_{\mathrm{eff}}\right)^{\boldsymbol{\theta}_{\boldsymbol{\mu}}} + \boldsymbol{C}_{\mathbf{S}} \cdot \left(\frac{q_{\mathrm{bm}}}{q_{\mathrm{im}} + q_{\mathrm{bm}}}\right)^{\boldsymbol{\theta}_{\boldsymbol{\mu}}} + \rho}{\mu_{\mathrm{x}}} \tag{4.214}$$

Velocity saturation reduction:

$$w_{\mathrm{sat}} = \frac{q_{\mathrm{im}} \cdot \xi_{\mathrm{tb}}}{\textbf{THESATT} + q_{\mathrm{im}} \cdot \xi_{\mathrm{tb}}} \tag{4.215}$$

$$\theta_{\mathrm{sat}}' = \begin{cases} \dfrac{\theta_{\mathrm{sat}}}{G_{\mathrm{mob}}} \cdot \left(1 + \textbf{THESATG} \cdot w_{\mathrm{sat}}\right) & \text{for } \textbf{THESATG} \geq 0 \\[2ex] \dfrac{\theta_{\mathrm{sat}}}{G_{\mathrm{mob}}} \cdot \dfrac{1}{1 - \textbf{THESATG} \cdot w_{\mathrm{sat}}} & \text{for } \textbf{THESATG} < 0 \end{cases} \tag{4.216}$$

4.2.11 Channel Length Modulation of Drain-Source Channel Current

In the remainder of this document, some variables (e.g., x_g) are labeled 'dc' or 'ac' (e.g., $x_\mathrm{g,dc}$ or $x_\mathrm{g,ac}$). Variables labeled 'dc' result from the *first* evaluation of Eqs. (4.109)–(4.216). For variables labeled 'ac', there are two possibilities. If **SWNUD** $= 1$, **SWDELVTAC** $= 1$ or **SWQSAT** $= 1$, their values result from the *second* evaluation of these equations. In any other case, their value is equal to their 'dc'-counterpart.
This applies to the following variables: x_g, V^*_SB, ϕ^*_T, x_ns, x_s, q_bs, V_dse, x_ds, q_bd, $\Delta\psi$, η_p, x_m, x_gm, q_im, α_m, q^*_im, q_bm, q_eff1, G_mob, θ'_sat.

Eqs. (4.217)-(4.220) are only calculated for $x_\mathrm{g,dc} > 0$:

$$S_\mathrm{1,dc} = \ln\left(\frac{1+\dfrac{V_\mathrm{DS}-\Delta\psi_\mathrm{dc}}{\mathbf{VP}}}{1+\dfrac{V_\mathrm{dse,dc}-\Delta\psi_\mathrm{dc}}{\mathbf{VP}}}\right) \tag{4.217}$$

$$S_\mathrm{2,dc} = \ln\left(1+\frac{V_\mathrm{dsx}}{\mathbf{VP}}\right) \tag{4.218}$$

$$\Delta L_\mathrm{dc}/L = \left(\mathbf{ALP}+\frac{\mathbf{ALP1}}{q^*_\mathrm{im,dc}}\right)\cdot\frac{q_\mathrm{im,dc}}{q^*_\mathrm{im,dc}}\cdot S_\mathrm{1,dc} + \mathbf{ALP2}\cdot q_\mathrm{bm,dc}\cdot\left(\phi^*_\mathrm{T,dc}\cdot\frac{\alpha_\mathrm{m,dc}}{q^*_\mathrm{im,dc}}\right)^2\cdot S_\mathrm{2,dc} \tag{4.219}$$

$$G_{\Delta L_\mathrm{dc}} = \frac{1}{1+\Delta L_\mathrm{dc}/L+(\Delta L_\mathrm{dc}/L)^2} \tag{4.220}$$

4.2.12 Drain-Source Channel Current

Eqs. (4.221)-(4.223) are only calculated for $x_\mathrm{g,dc} > 0$:

Velocity saturation:

$$\theta^*_\mathrm{sat,dc} = \frac{\theta'_\mathrm{sat,dc}}{G_{\Delta L_\mathrm{dc}}} \tag{4.221}$$

$$z_\mathrm{sat,dc} = \begin{cases} \left(\theta^*_\mathrm{sat,dc}\cdot\Delta\psi_\mathrm{dc}\right)^2 & \text{for NMOS} \\ \dfrac{\left(\theta^*_\mathrm{sat,dc}\cdot\Delta\psi_\mathrm{dc}\right)^2}{1+\theta^*_\mathrm{sat,dc}\cdot\Delta\psi_\mathrm{dc}} & \text{for PMOS} \end{cases} \tag{4.222}$$

$$G_\mathrm{vsat,dc} = \frac{G_\mathrm{mob,dc}\cdot G_{\Delta L_\mathrm{dc}}}{2}\cdot\left(1+\sqrt{1+2\cdot z_\mathrm{sat,dc}}\right) \tag{4.223}$$

Drain-Source channel current:

$$I_\mathrm{DS} = \begin{cases} 0 & \text{for } x_\mathrm{g,dc} \le 0 \\ \beta\cdot\dfrac{q^*_\mathrm{im,dc}}{G_\mathrm{vsat,dc}}\cdot\Delta\psi_\mathrm{dc} & \text{for } x_\mathrm{g,dc} > 0 \end{cases} \tag{4.224}$$

Variables related to the gate to channel current and thermal channel noise (these variables are calculated if $x_{\mathrm{g,dc}} > 0$):

$$V_{\mathrm{oxm,dc}} = \phi^*_{\mathrm{T,dc}} \cdot x_{\mathrm{gm,dc}} \tag{4.225}$$

$$\alpha'_{\mathrm{m,dc}} = \alpha_{\mathrm{m,dc}} \cdot \left[1 + \frac{z_{\mathrm{sat,dc}}}{2} \cdot \left(\frac{G_{\mathrm{mob,dc}} \cdot G_{\Delta L_{\mathrm{dc}}}}{G_{\mathrm{vsat,dc}}}\right)^2\right] \tag{4.226}$$

$$H_{\mathrm{dc}} = \frac{G_{\mathrm{mob,dc}} \cdot G_{\Delta L_{\mathrm{dc}}}}{G_{\mathrm{vsat,dc}}} \cdot \frac{q^*_{\mathrm{im,dc}}}{\alpha'_{\mathrm{m,dc}}} \tag{4.227}$$

4.2.13 Surface Potential in Gate Overlap Regions

At the source side:

$$x_{\mathrm{sov}}\left(x_{\mathrm{g}}\right) = \begin{cases} x'_{\mathrm{g}} = \left(x_{\mathrm{g}} + \sqrt{x_{\mathrm{g}}^2 + \boldsymbol{\varepsilon_{\mathrm{ov}}}^2}\right) \Big/ 2 \\ x_{\mathrm{sov}} = -x'_{\mathrm{g}} - \boldsymbol{G_{\mathrm{ov}}}^2/2 + \boldsymbol{G_{\mathrm{ov}}} \cdot \sqrt{x'_{\mathrm{g}} + \boldsymbol{G_{\mathrm{ov}}}^2/4 + \boldsymbol{a_{\mathrm{ov}}}} + \boldsymbol{\delta_{\mathrm{ov}}} \end{cases} \tag{4.228}$$

$$\psi_{\mathrm{sov}} = -\boldsymbol{\phi}_{\mathbf{T}_{\mathrm{A}}} \cdot x_{\mathrm{sov}}\left(-\frac{V_{\mathrm{GS}}}{\boldsymbol{\phi}_{\mathbf{T}_{\mathrm{A}}}}\right) \tag{4.229}$$

$$V_{\mathrm{ov_0}} = V_{\mathrm{GS}} - \psi_{\mathrm{sov}} \tag{4.230}$$

At the drain side:

$$x_{\mathrm{dov}}\left(x_{\mathrm{g}}\right) = \begin{cases} x'_{\mathrm{g}} = \left(x_{\mathrm{g}} + \sqrt{x_{\mathrm{g}}^2 + \boldsymbol{\varepsilon_{\mathrm{dov}}}^2}\right) \Big/ 2 \\ x_{\mathrm{dov}} = -x'_{\mathrm{g}} - \boldsymbol{G_{\mathrm{dov}}}^2/2 + \boldsymbol{G_{\mathrm{dov}}} \cdot \sqrt{x'_{\mathrm{g}} + \boldsymbol{G_{\mathrm{dov}}}^2/4 + \boldsymbol{a_{\mathrm{dov}}}} + \boldsymbol{\delta_{\mathrm{dov}}} \end{cases} \tag{4.231}$$

$$\psi_{\mathrm{dov}} = -\boldsymbol{\phi}_{\mathbf{T}_{\mathrm{A}}} \cdot x_{\mathrm{dov}}\left(-\frac{V_{\mathrm{GS}} - V_{\mathrm{DS}}}{\boldsymbol{\phi}_{\mathbf{T}_{\mathrm{A}}}}\right) \tag{4.232}$$

$$V_{\mathrm{ov_L}} = V_{\mathrm{GS}} - V_{\mathrm{DS}} - \psi_{\mathrm{dov}} \tag{4.233}$$

4.2.14 Gate Current

The equations in this Section are only calculated when **SWIGATE** $= 1$.

Source/Drain gate overlap current:

$$I_{\mathrm{GXov}}(V_{\mathrm{GX}},\,\psi,\,V_{\mathrm{ov}},\,B_{\mathrm{ovx}},\,I_{\mathrm{G}}) = \begin{cases} V^*_{\mathrm{ov}} = \sqrt{V^2_{\mathrm{ov}} + 10^{-6}} \\ z_{\mathrm{g}} = \begin{cases} \mathrm{MINA}\left(\dfrac{V^*_{\mathrm{ov}}}{\mathbf{CHIB}},\,\boldsymbol{GC}_{\mathbf{Q,ov}},\,10^{-6}\right) & \text{for } \boldsymbol{gc}_{\mathbf{3,ov}} < 0 \\ \dfrac{V^*_{\mathrm{ov}}}{\mathbf{CHIB}} & \text{for } \boldsymbol{gc}_{\mathbf{3,ov}} \geq 0 \end{cases} \\ F_{\mathrm{S1}} = \dfrac{3\cdot\boldsymbol{\phi}_{\mathbf{T}_{\mathrm{A}}} + \psi}{\boldsymbol{\phi}_{\mathbf{T}_{\mathrm{A}}}} \\ F_{\mathrm{S2}} = -3 - \mathbf{GCO} \\ F_{\mathrm{S3}} = 30\cdot V_{\mathrm{GX}} \\ F_{\mathrm{Sov}} = \mathrm{MXE}\left(F_{\mathrm{S2}},\,\mathrm{MNE}\left(F_{\mathrm{S1}},\,F_{\mathrm{S3}},\,0.9\right),\,0.3\right) \\ I_{\mathrm{Gov}} = I_{\mathrm{G}}\cdot F_{\mathrm{Sov}}\cdot \\ \qquad \exp\left(B_{\mathrm{ovx}}\cdot\left[-\dfrac{3}{2} + z_{\mathrm{g}}\cdot\left(\boldsymbol{gc}_{\mathbf{2,ov}} + \boldsymbol{gc}_{\mathbf{3,ov}}\cdot z_{\mathrm{g}}\right)\right]\right) \end{cases} \tag{4.234}$$

$$I_{\mathrm{GSov}} = I_{\mathrm{GXov}}\left(V_{\mathrm{GS}},\,\psi_{\mathrm{sov}},\,V_{\mathrm{ov_0}},\,\boldsymbol{B}_{\mathbf{ov}},\,\boldsymbol{I}_{\mathbf{GOV}}\right) \tag{4.235}$$

$$I_{\mathrm{GDov}} = I_{\mathrm{GXov}}\left(V_{\mathrm{GS}} - V_{\mathrm{DS}},\,\psi_{\mathrm{dov}},\,V_{\mathrm{ov_L}},\,\boldsymbol{B}_{\mathbf{ovd}},\,\boldsymbol{I}_{\mathbf{GOVD}}\right) \tag{4.236}$$

Gate-channel current:

$$V_{\mathrm{m}} = V^*_{\mathrm{SB,dc}} + \phi^*_{\mathrm{T,dc}}\cdot\left[\frac{x_{\mathrm{ds,dc}}}{2} - \ln\left(\frac{1 + \exp(x_{\mathrm{ds,dc}} - V_{\mathrm{dse,dc}}/\phi^*_{\mathrm{T,dc}})}{2}\right)\right] \tag{4.237}$$

$$D_{\mathrm{ch}} = \mathbf{GCO}\cdot\phi^*_{\mathrm{T,dc}} \tag{4.238}$$

$$\psi_{\mathrm{t}} = \mathrm{MINA}\left(0,\,V_{\mathrm{oxm,dc}} + D_{\mathrm{ch}},\,0.01\right) \tag{4.239}$$

$$V^*_{\mathrm{oxm}} = \sqrt{V^2_{\mathrm{oxm,dc}} + 10^{-6}} \tag{4.240}$$

$$z_{\mathrm{g}} = \begin{cases} \mathrm{MINA}\left(\dfrac{V^*_{\mathrm{oxm,dc}}}{\mathbf{CHIB}},\,\boldsymbol{GC}_{\mathbf{Q}},\,10^{-6}\right) & \text{for } \mathbf{GC3} < 0 \\ \dfrac{V^*_{\mathrm{oxm,dc}}}{\mathbf{CHIB}} & \text{for } \mathbf{GC3} \geq 0 \end{cases} \tag{4.241}$$

$$\Delta_{\mathrm{Si}} = \exp\left(x_{\mathrm{m,dc}} - \frac{\boldsymbol{\alpha}_{\mathbf{b}} + V_{\mathrm{m}} - \psi_{\mathrm{t}}}{\phi^*_{\mathrm{T,dc}}}\right) \tag{4.242}$$

$$F_{\mathrm{S}} = \ln\left[\frac{1 + \Delta_{\mathrm{Si}}}{1 + \Delta_{\mathrm{Si}}\cdot\exp\left(-\dfrac{V_{\mathrm{GS}} + V^*_{\mathrm{SB,dc}} - V_{\mathrm{m}}}{\phi^*_{\mathrm{T,dc}}}\right)}\right] \tag{4.243}$$

$$I_{\mathrm{GCO}} = \boldsymbol{I}_{\mathbf{GINV}}\cdot F_{\mathrm{S}}\cdot\exp\left(\boldsymbol{B}\cdot\left[-3/2 + z_{\mathrm{g}}\cdot\left(\mathbf{GC2} + \mathbf{GC3}\cdot z_{\mathrm{g}}\right)\right]\right) \tag{4.244}$$

$$\text{if } x_{\mathrm{g,dc}} > 0 \begin{cases} u_0 = \mathbf{CHIB} / \left[\boldsymbol{B} \cdot (\mathbf{GC2} + 2 \cdot \mathbf{GC3} \cdot z_{\mathrm{g}}) \right] \\ x = \Delta\psi_{\mathrm{dc}} / \left(2 \cdot u_0\right) \\ b = u_0 / H_{\mathrm{dc}} \\ B_{\mathrm{g}} = b \cdot (1 - b) / 2 \\ A_{\mathrm{g}} = 1/2 - 3 \cdot B_{\mathrm{g}} \\ p_{\mathrm{gc}} = (1 - b) \cdot \dfrac{\sinh(x)}{x} + b \cdot \cosh(x) \\ p_{\mathrm{gd}} = \dfrac{p_{\mathrm{gc}}}{2} - B_{\mathrm{g}} \cdot \sinh(x) - A_{\mathrm{g}} \cdot \dfrac{\sinh(x)}{x} \cdot \left[\coth(x) - \dfrac{1}{x} \right] \end{cases} \tag{4.245}$$

$$\text{if } x_{\mathrm{g,dc}} \leq 0 \begin{cases} p_{\mathrm{gc}} = 1 \\ p_{\mathrm{gd}} = 1/2 \end{cases} \tag{4.246}$$

$$S_{\mathrm{g}} = \frac{1}{2} \cdot \left(1 + \frac{x_{\mathrm{g,dc}}}{\sqrt{x_{\mathrm{g,dc}}^2 + 10^{-6}}} \right) \tag{4.247}$$

$$I_{\mathrm{GC}} = I_{\mathrm{GCO}} \cdot p_{\mathrm{gc}} \cdot S_{\mathrm{g}} \tag{4.248}$$

$$I_{\mathrm{GCD}} = I_{\mathrm{GCO}} \cdot p_{\mathrm{gd}} \cdot S_{\mathrm{g}} \tag{4.249}$$

$$I_{\mathrm{GCS}} = I_{\mathrm{GC}} - I_{\mathrm{GCD}} \tag{4.250}$$

$$I_{\mathrm{GB}} = I_{\mathrm{GCO}} \cdot p_{\mathrm{gc}} \cdot (1 - S_{\mathrm{g}}) \tag{4.251}$$

4.2.15 Gate-Induced Drain/Source Leakage Current

The equations in this section are only calculated when **SWGIDL** $= 1$.

$$I_{\mathrm{gixl}}(V_{\mathrm{ov}},\, V_{\mathrm{XB}},\, A,\, B,\, C) = \begin{cases} V_{\mathrm{tov}} = \sqrt{V_{\mathrm{ov}}^2 + C^2 \cdot {V_{\mathrm{XB}}}^2 + 10^{-6}} \\ t = V_{\mathrm{XB}} \cdot V_{\mathrm{tov}} \cdot V_{\mathrm{ov}} \\ I_{\mathrm{gisl}} = \begin{cases} -A \cdot t \cdot \exp\left(-\dfrac{B}{V_{\mathrm{tov}}} \right) & \text{for } V_{\mathrm{ov}} < 0 \\ 0 & \text{for } V_{\mathrm{ov}} \geq 0 \end{cases} \end{cases} \tag{4.252}$$

$$I_{\mathrm{gisl}} = I_{\mathrm{gixl}}(V_{\mathrm{ov}_0},\, V_{\mathrm{SB}},\, \boldsymbol{A}_{\mathbf{GIDL}},\, \boldsymbol{B}_{\mathbf{GIDL}},\, \mathbf{CGIDL}) \tag{4.253}$$

$$I_{\mathrm{gidl}} = I_{\mathrm{gixl}}(V_{\mathrm{ov}_{\mathrm{L}}},\, V_{\mathrm{DS}} + V_{\mathrm{SB}},\, \boldsymbol{A}_{\mathbf{GIDLD}},\, \boldsymbol{B}_{\mathbf{GIDLD}},\, \mathbf{CGIDLD}) \tag{4.254}$$

4.2.16 Edge Transistor Current

The equations in this Section are only calculated when **SWEDGE** $= 1$ and **BETNEDGE** > 0.

$$\phi_{\mathrm{V,edge}} = \mathrm{MINA}\left(V_{\mathrm{SB}},\, V_{\mathrm{SB}} + V_{\mathrm{DS}},\, \boldsymbol{b}_{\boldsymbol{\phi},\mathbf{edge}}\right) + \boldsymbol{\phi}_{\mathbf{X,edge}} \tag{4.255}$$

$$V^*_{\mathrm{SB,edge}} = V_{\mathrm{SB}} - \mathrm{MINA}\left(\phi_{\mathrm{V,edge}},\, 0,\, \boldsymbol{a_{\phi,\mathrm{edge}}}\right) + \boldsymbol{\phi_{\mathrm{X,edge}}}^* \tag{4.256}$$

$$V_{\mathrm{sbx,edge}} = V^*_{\mathrm{SB,edge}} + 0.5 \cdot (V_{\mathrm{DS}} - V_{\mathrm{dsx}}) \tag{4.257}$$

$$n_{\mathrm{SCE,edge}} = 1 + \mathbf{PSCEEDGE} \cdot (1 + \mathbf{PSCEDEDGE} \cdot V_{\mathrm{dsx}}) \cdot (1 + \mathbf{PSCEBEDGE} \cdot V_{\mathrm{sbx,edge}}) \tag{4.258}$$

$$\phi^*_{\mathrm{T,edge}} = \boldsymbol{\phi_{\mathrm{T0,edge}}}^* \cdot n_{\mathrm{SCE,edge}} \tag{4.259}$$

$$V^*_{\mathrm{ds,edge}} = \frac{2 \cdot V_{\mathrm{dsx}}}{1 + \sqrt{1 + \mathbf{CFDEDGE} \cdot V_{\mathrm{dsx}}}} \tag{4.260}$$

$$\Delta V_{\mathrm{G,edge}} = \mathbf{CFEDGE} \cdot V^*_{\mathrm{ds,edge}} \cdot (1 + \mathbf{CFBEDGE} \cdot V_{\mathrm{sbx,edge}}) \tag{4.261}$$

$$V^*_{\mathrm{GB,edge}} = V_{\mathrm{GB}} + \Delta V_{\mathrm{G,edge}} - \boldsymbol{V_{\mathrm{FB,edge}}} \tag{4.262}$$

$$x_{\mathrm{g,edge}} = V^*_{\mathrm{GB,edge}} / \phi^*_{\mathrm{T,edge}} \tag{4.263}$$

$$x_{\mathrm{b,edge}} = \boldsymbol{\phi_{\mathrm{B,edge}}} / \phi^*_{\mathrm{T,edge}} \tag{4.264}$$

$$\Delta x_{\mathrm{th,edge}} = 2 \cdot ln\left(\frac{x_{\mathrm{b,edge}}}{\boldsymbol{G_{\mathrm{edge}}}} + \sqrt{x_{\mathrm{b,edge}}}\right) \tag{4.265}$$

Inversion charge at the source side:

$$x_{\mathrm{n,edge,s}} = V^*_{\mathrm{SB,edge}} / \phi^*_{\mathrm{T,edge}} \tag{4.266}$$

$$\begin{cases}
x_{\mathrm{sth,edge,s}} = x_{\mathrm{b,edge}} + x_{\mathrm{n,edge,s}} \\
x_{\mathrm{th0,edge,s}} = x_{\mathrm{sth,edge,s}} + \boldsymbol{G_{\mathrm{edge}}} \cdot \sqrt{x_{\mathrm{sth,edge,s}}} \\
x_{\mathrm{th,edge,s}} = x_{\mathrm{th0,edge,s}} + \Delta x_{\mathrm{th,edge}} \\
n_{\mathrm{edge,s}} = 1 + \dfrac{\boldsymbol{G_{\mathrm{edge}}}}{2 \cdot \sqrt{x_{\mathrm{sth,edge,s}}}} \\
x_{\mathrm{gt,edge,s}} = x_{\mathrm{g,edge}} - x_{\mathrm{th,edge,s}} \\
x_{\mathrm{gt0,edge,s}} = x_{\mathrm{gt,edge,s}} + ln\left(\boldsymbol{G_{\mathrm{edge}}}^2\right) - 1 \\
x^*_{\mathrm{gt0,edge,s}} = \dfrac{1}{2} \cdot \left(x_{\mathrm{gt0,edge,s}} + \sqrt{x^2_{\mathrm{gt0,edge,s}} + 10}\right) \\
q_{\mathrm{i0si,edge,s}} = x_{\mathrm{gt,edge,s}} - n_{\mathrm{edge,s}} \cdot ln\left(x^*_{\mathrm{gt0,edge,s}}\right) + ln\left(\boldsymbol{G_{\mathrm{edge}}}^2\right) \\
q_{\mathrm{i0,edge,s}} = \dfrac{1}{2} \cdot \left(q_{\mathrm{i0si,edge,s}} + \sqrt{q^2_{\mathrm{i0si,edge,s}} + 2}\right) \\
\Delta_{\mathrm{0,edge,s}} = \left(\boldsymbol{G_{\mathrm{edge}}}^2 \cdot exp\left(x_{\mathrm{gt,edge,s}} - q_{\mathrm{i0,edge,s}}\right)\right)^{1/n_{\mathrm{edge,s}}} \\
q_{\mathrm{ieff,edge,s}} = q_{\mathrm{i0,edge,s}} - n_{\mathrm{edge,s}} \cdot \\
\qquad \left(\dfrac{\sqrt{n^2_{\mathrm{edge,s}} + (2 \cdot (q_{\mathrm{i0,edge,s}} + n_{\mathrm{edge,s}}) - \Delta_{\mathrm{0,edge,s}}) \cdot \Delta_{\mathrm{0,edge,s}}} - n_{\mathrm{edge,s}}}{\Delta_{\mathrm{0,edge,s}}} - 1\right)
\end{cases} \tag{4.267}$$

Inversion charge at the drain side:

$$x_{\mathrm{n,edge,d}} = \left(V_{\mathrm{dse}} + V^*_{\mathrm{SB,edge}}\right) / \phi^*_{\mathrm{T,edge}} \tag{4.268}$$

if $q_{\text{ieff,edge,s}} < 10^{-3}$ and $V_{\text{dse}} < 10^{-6}$

$$\begin{cases} q_{\text{ieff,edge,ds}} = q_{\text{ieff,edge,s}} \cdot \left(exp\left(x_{\text{n,edge,s}} - x_{\text{n,edge,d}}\right) - 1\right) \\ q_{\text{ieff,edge,d}} = q_{\text{ieff,edge,ds}} + q_{\text{ieff,edge,s}} \end{cases} \tag{4.269}$$

else

$$\begin{cases} x_{\text{sth,edge,d}} = x_{\text{b,edge}} + x_{\text{n,edge,d}} \\ x_{\text{th0,edge,d}} = x_{\text{sth,edge,d}} + \boldsymbol{G_{\text{edge}}} \cdot \sqrt{x_{\text{sth,edge,d}}} \\ x_{\text{th,edge,d}} = x_{\text{th0,edge,d}} + \Delta x_{\text{th,edge}} \\ n_{\text{edge,d}} = 1 + \dfrac{\boldsymbol{G_{\text{edge}}}}{2 \cdot \sqrt{x_{\text{sth,edge,d}}}} \\ x_{\text{gt,edge,d}} = x_{\text{g,edge}} - x_{\text{th,edge,d}} \\ x_{\text{gt0,edge,d}} = x_{\text{gt,edge,d}} + ln\left(\boldsymbol{G_{\text{edge}}}^2\right) - 1 \\ x^*_{\text{gt0,edge,d}} = \dfrac{1}{2} \cdot \left(x_{\text{gt0,edge,d}} + \sqrt{x^2_{\text{gt0,edge,d}} + 10}\right) \\ q_{\text{i0si,edge,d}} = x_{\text{gt,edge,d}} - n_{\text{edge,d}} \cdot ln\left(x^*_{\text{gt0,edge,d}}\right) + ln\left(\boldsymbol{G_{\text{edge}}}^2\right) \\ q_{\text{i0,edge,d}} = \dfrac{1}{2} \cdot \left(q_{\text{i0si,edge,d}} + \sqrt{q^2_{\text{i0si,edge,d}} + 2}\right) \\ \Delta_{\text{0,edge,d}} = \left(\boldsymbol{G_{\text{edge}}}^2 \cdot exp\left(x_{\text{gt,edge,d}} - q_{\text{i0,edge,d}}\right)\right)^{1/n_{\text{edge,d}}} \\ q_{\text{ieff,edge,d}} = q_{\text{i0,edge,d}} - n_{\text{edge,d}} \cdot \\ \qquad \left(\dfrac{\sqrt{n^2_{\text{edge,d}} + \left(2 \cdot \left(q_{\text{i0,edge,d}} + n_{\text{edge,d}}\right) - \Delta_{\text{0,edge,d}}\right) \cdot \Delta_{\text{0,edge,d}}} - n_{\text{edge,d}}}{\Delta_{\text{0,edge,d}}} - 1\right) \end{cases} \tag{4.270}$$

Drain to source current:

$$q_{\text{ieff,edge,ds}} = q_{\text{ieff,edge,d}} - q_{\text{ieff,edge,s}} \tag{4.271}$$

$$q_{\text{ieff,edge,m}} = \frac{q_{\text{ieff,edge,d}} + q_{\text{ieff,edge,s}}}{2} \tag{4.272}$$

$$\alpha_{\text{mb,edge}} = 1 - \frac{1}{2} \cdot \frac{\boldsymbol{G_{\text{edge}}}}{\sqrt{x_{\text{g,edge}} - q_{\text{ieff,edge,m}} + \frac{1}{4} \cdot \boldsymbol{G_{\text{edge}}}^2}} \tag{4.273}$$

$$I_{\text{DSedge}} = -\frac{\boldsymbol{\beta_{\text{edge}}} \cdot \phi^{*2}_{\text{T,edge}}}{G_{\text{mob}}} \cdot \left(\alpha_{\text{mb,edge}} \cdot q_{\text{ieff,edge,m}} + 1\right) \cdot q_{\text{ieff,edge,ds}} \tag{4.274}$$

4.2.17 Impact Ionization or Weak-Avalanche

The equations in this Section are only calculated when **SWIMPACT** $= 1$ and $x_{\text{g,dc}} > 0$.

$$a_2^* = \boldsymbol{a_2} \cdot \left[1 + \mathbf{A4} \cdot \left(\sqrt{V^*_{\text{SB,dc}} + \boldsymbol{\phi_{\text{B}}}} - \sqrt{\boldsymbol{\phi_{\text{B}}}}\right)\right] \tag{4.275}$$

$$\Delta V_{\text{sat}} = V_{\text{DS}} - \mathbf{A3} \cdot \Delta\psi_{\text{dc}} \tag{4.276}$$

$$M_{\mathrm{avl}} = \begin{cases} 0 & \text{for } \Delta V_{\mathrm{sat}} \leq 0 \\ \mathbf{A1} \cdot \Delta V_{\mathrm{sat}} \cdot \exp\left(-\dfrac{a_2^*}{\Delta V_{\mathrm{sat}}}\right) & \text{for } \Delta V_{\mathrm{sat}} > 0 \end{cases} \tag{4.277}$$

$$I_{\mathrm{avl}} = M_{\mathrm{avl}} \cdot (I_{\mathrm{DS}} + I_{\mathrm{DS,edge}}) \tag{4.278}$$

4.2.18 Total Terminal Currents

$$I_{\mathrm{D}} = I_{\mathrm{DS}} + I_{\mathrm{DSedge}} + I_{\mathrm{avl}} - I_{\mathrm{GDov}} - I_{\mathrm{GCD}} + I_{\mathrm{gidl}} \tag{4.279}$$

$$I_{\mathrm{S}} = -I_{\mathrm{DS}} - I_{\mathrm{DSedge}} - I_{\mathrm{GSov}} - I_{\mathrm{GCS}} + I_{\mathrm{gisl}} \tag{4.280}$$

$$I_{\mathrm{G}} = I_{\mathrm{GC}} + I_{\mathrm{GB}} + I_{\mathrm{GDov}} + I_{\mathrm{GSov}} \tag{4.281}$$

$$I_{\mathrm{B}} = -I_{\mathrm{avl}} - I_{\mathrm{GB}} - I_{\mathrm{gidl}} - I_{\mathrm{gisl}} \tag{4.282}$$

4.3 Charge Model

In this section, the charge model equations of the PSP-model are given. Use is made of the applied terminal bias values V_{GS}, V_{DS} and V_{SB}, the local parameters listed in Section 2.5.2 and the internal parameters introduced in Section 4.1. Local parameters are denoted by capital characters in bold font, whereas internal (bias-independent) parameters are denoted by symbols in bold font. The definitions of the auxiliary functions MINA(.), MAXA(.), $\chi(.)$ and $\sigma_{1,2}(.)$ can be found in Appendix A.

4.3.1 Quantum-Mechanical Corrections

$$V_{\mathrm{oxm,ac}} = \phi^*_{\mathrm{T,ac}} \cdot x_{\mathrm{gm,ac}} \tag{4.283}$$

$$q_{\mathrm{eff,ac}} = \begin{cases} V_{\mathrm{oxm,ac}} & \text{for } x_{\mathrm{g,ac}} \leq 0 \\ q_{\mathrm{eff1,ac}} & \text{for } x_{\mathrm{g,ac}} > 0 \end{cases} \tag{4.284}$$

$$C^{qm}_{\mathrm{OX}} = \begin{cases} \mathbf{COX} & \text{for } q_{\mathrm{q}} = 0 \\ \dfrac{\mathbf{COX}}{1 + q_{\mathrm{q}}/({q_{\mathrm{eff,ac}}}^2 + {q_{\mathrm{lim}}}^2)^{1/6}} & \text{for } q_{\mathrm{q}} > 0 \end{cases} \tag{4.285}$$

4.3.2 Intrinsic Charge Model

Channel length modulation: Eqs. (4.286)-(4.288) are only calculated for $x_{\mathrm{g,ac}} > 0$:

$$S_{1,\mathrm{ac}} = \ln\left(\frac{1 + \dfrac{V_{\mathrm{DS}} - \Delta\psi_{\mathrm{ac}}}{\mathbf{VP}}}{1 + \dfrac{V_{\mathrm{dse,ac}} - \Delta\psi_{\mathrm{ac}}}{\mathbf{VP}}}\right) \tag{4.286}$$

$$\Delta L_{\mathrm{ac}}/L = \left(\mathbf{ALPAC} + \frac{\mathbf{ALP1AC}}{q^*_{\mathrm{im,ac}}}\right) \cdot \frac{q_{\mathrm{im,ac}}}{q^*_{\mathrm{im,ac}}} \cdot S_{1,\mathrm{ac}} \tag{4.287}$$

$$G_{\Delta L_{\mathrm{ac}}} = \begin{cases} 1/(1 + \Delta L_{\mathrm{ac}}/L + (\Delta L_{\mathrm{ac}}/L)^2) & \text{if } \Delta L_{\mathrm{ac}}/L > 0 \\ 1 - \Delta L_{\mathrm{ac}}/L & \text{else} \end{cases} \tag{4.288}$$

Variables related to the charge partitioning: Eqs. (4.289)-(4.291) are only calculated for $x_{\mathrm{g,ac}} > 0$:

$$\theta^*_{\mathrm{sat,ac}} = \frac{\theta'_{\mathrm{sat,ac}}}{G_{\Delta L_{\mathrm{ac}}}} \tag{4.289}$$

$$z_{\mathrm{sat,ac}} = \begin{cases} \left(\theta^*_{\mathrm{sat,ac}} \cdot \Delta\psi_{\mathrm{ac}}\right)^2 & \text{for NMOS} \\ \dfrac{\left(\theta^*_{\mathrm{sat,ac}} \cdot \Delta\psi_{\mathrm{ac}}\right)^2}{1 + \theta^*_{\mathrm{sat,ac}} \cdot \Delta\psi_{\mathrm{ac}}} & \text{for PMOS} \end{cases} \tag{4.290}$$

$$G_{\mathrm{vsat,ac}} = \frac{G_{\mathrm{mob,ac}} \cdot G_{\Delta L_{\mathrm{ac}}}}{2} \cdot \left(1 + \sqrt{1 + 2 \cdot z_{\mathrm{sat,ac}}}\right) \tag{4.291}$$

$$\alpha'_{\rm m,ac} = \alpha_{\rm m,ac} \cdot \left[1 + \frac{z_{\rm sa,act}}{2} \cdot \left(\frac{G_{\rm mob,ac} \cdot G_{\Delta L_{\rm ac}}}{G_{\rm vsat,ac}}\right)^2\right] \tag{4.292}$$

$$H_{\rm ac} = \frac{G_{\rm mob,ac} \cdot G_{\Delta L_{\rm ac}}}{G_{\rm vsat,ac}} \cdot \frac{q^*_{\rm im,ac}}{\alpha'_{\rm m,ac}} \tag{4.293}$$

Intrinsic charges if $x_{\rm g,ac} < 0$:

$$q_{\Delta \rm L} = \begin{cases} 0 & \text{if } \textbf{SWQPART} = 1 \\ \left(1 - G_{\Delta L_{\rm ac}}\right) \cdot \left(q_{\rm im,ac} - \alpha_{\rm m,ac} \cdot \Delta\psi_{\rm ac}/2\right) & \text{else} \end{cases} \tag{4.294}$$

$$Q_{\Delta \rm L} = C_{\rm OX}^{\rm qm} \cdot q_{\Delta \rm L} \tag{4.295}$$

$$Q^*_{\Delta \rm L} = Q_{\Delta \rm L} \cdot \left(1 + G_{\Delta L_{\rm ac}}\right) \tag{4.296}$$

$$F_{\rm j} = \Delta\psi_{\rm ac} / \left(2 \cdot H_{\rm ac}\right) \tag{4.297}$$

$$Q'^{(i)}_G = C_{OX}^{qm} \cdot \left[V_{oxm,ac} + \frac{\eta_{p,ac} \cdot \Delta\psi_{ac}}{2} \cdot \left(\frac{G_{\Delta L_{ac}}}{3} \cdot F_j + G_{\Delta L_{ac}} - 1\right)\right] \tag{4.298}$$

$$Q'^{(i)}_{\rm D} = \begin{cases} -C_{\rm OX}^{\rm qm} \cdot \dfrac{G^2_{\Delta L_{\rm ac}}}{2} \cdot \left(q_{\rm im,ac} + \dfrac{\alpha_{\rm m,ac} \cdot \Delta\psi_{\rm ac}}{2} \cdot \left[F_{\rm j} - 2\right]\right) & \text{if } \textbf{SWQPART} = 1 \\ -C_{\rm OX}^{\rm qm} \cdot \dfrac{G^2_{\Delta L_{\rm ac}}}{2} \cdot & \\ \left(q_{\rm im,ac} + \dfrac{\alpha_{\rm m,ac} \cdot \Delta\psi_{\rm ac}}{6} \cdot \left[\dfrac{F_{\rm j}^2}{5} + F_{\rm j} - 1\right]\right) - Q^*_{\Delta \rm L} & \text{else} \end{cases} \tag{4.299}$$

$$Q'^{(i)}_{\rm I} = -C_{\rm OX}^{\rm qm} \cdot G_{\Delta L_{\rm ac}} \cdot \left(q_{\rm im,ac} + \frac{\alpha_{\rm m,ac} \cdot \Delta\psi_{\rm ac}}{6} \cdot F_{\rm j}\right) - Q_{\Delta \rm L} \tag{4.300}$$

Intrinsic charges if $x_{\rm g,ac} \leq 0$:

$$Q'^{(i)}_{\rm G} = C_{\rm OX}^{\rm qm} \cdot V_{\rm oxm,ac} \tag{4.301}$$

$$Q'^{(i)}_{\rm D} = 0 \tag{4.302}$$

$$Q'^{(i)}_{\rm I} = 0 \tag{4.303}$$

4.3.3 Inner Fringe Charge Model

$$V_{\rm g,inr} = V^*_{\rm GB} - \textbf{DVFBINR} + \boldsymbol{V}_{\rm inr,max} \tag{4.304}$$

$$V_{\rm x1,inr} = \mathrm{MAXA}\left(V_{\rm g,inr}, \boldsymbol{V_{\rm inr,max}}, \boldsymbol{a_{\rm inr}}\right) \tag{4.305}$$

$$V_{\rm x2,inr} = V_{\rm x1,inr} \cdot \left(2 \cdot V_{\rm x1,inr} - \boldsymbol{V_{\rm inr,max}} - V_{\rm g,inr}\right) \tag{4.306}$$

$$V_{\rm g,inr,eff} = \frac{V_{\rm g,inr} \cdot \boldsymbol{V_{\rm inr,max}}}{V_{\rm x1,inr}} \tag{4.307}$$

$$f_{\mathrm{q,inr}} = \sqrt{1 - \mathbf{FCINRACC} \cdot V_{\mathrm{g,inr,eff}}} \tag{4.308}$$

$$f_{\mathrm{inr,acc}} = \left(\frac{1}{2 \cdot f_{\mathrm{q,inr}}} - 1\right) \cdot \frac{V_{\mathrm{x2,inr}} + V_{\mathrm{g,inr}} \cdot (\boldsymbol{V}_{\mathbf{inr,max}} - V_{\mathrm{x1,inr}})}{V_{\mathrm{x2,inr}}} \cdot \frac{\boldsymbol{V}_{\mathbf{inr,max}}}{V_{\mathrm{x1,inr}}} + 1 \tag{4.309}$$

$$\Delta V_{\mathrm{inr,acc}} = \frac{1 - f_{\mathrm{q,inr}}}{\mathbf{FCINRACC}} + V_{\mathrm{g,inr}} - V_{\mathrm{g,inr,eff}} \tag{4.310}$$

$$x_{\mathrm{g,inr,dep}} = \frac{V^*_{\mathrm{GB}}}{0.5 \cdot \boldsymbol{\phi}_{\mathbf{B,ac}} + \phi^*_{\mathrm{T,ac}} \cdot \left(1 + G_{\mathrm{ac}}/\sqrt{2}\right)} \tag{4.311}$$

$$f_{\mathrm{inr,dep}} = \frac{1}{1 + \exp\left(-x_{\mathrm{g,inr,dep}}\right)} \tag{4.312}$$

$$\Delta V_{\mathrm{inr,dep}} = \frac{V^*_{\mathrm{GB}}}{x_{\mathrm{g,inr,dep}}} \cdot \ln\left(1 + \exp\left(x_{\mathrm{g,inr,dep}}\right)\right) \tag{4.313}$$

$$f_{\mathrm{inr}} = \mathbf{FCINRDEP} \cdot (f_{\mathrm{inr,dep}} - f_{\mathrm{inr,acc}}) + f_{\mathrm{inr,acc}} \tag{4.314}$$

$$\Delta V_{\mathrm{inr}} = \mathbf{FCINRDEP} \cdot (\Delta V_{\mathrm{inr,dep}} - \Delta V_{\mathrm{inr,acc}}) + \Delta V_{\mathrm{inr,acc}} \tag{4.315}$$

$$V_{\mathrm{gs,inr}} = V^*_{\mathrm{GB}} - \phi^*_{\mathrm{T,ac}} \cdot x_{\mathrm{n0s,ac}} + V_{oxm,ac} - \frac{\Delta\psi_{\mathrm{ac}}}{2} \tag{4.316}$$

$$V_{\mathrm{sg,inr}} = V^*_{\mathrm{GB}} - V_{\mathrm{gs,inr}} - q_{\mathrm{bs,ac}} \tag{4.317}$$

$$V_{\mathrm{gd,inr}} = \Delta\psi_{\mathrm{ac}} + V_{\mathrm{gs,inr}} - V_{\mathrm{DS}} \tag{4.318}$$

$$V_{\mathrm{dg,inr}} = V^*_{\mathrm{GB}} - V_{\mathrm{gd,inr}} - q_{\mathrm{bd,ac}} \tag{4.319}$$

$$Q_{\mathrm{g,inr}} = f_{\mathrm{inr}} \cdot (\mathbf{CINRD} \cdot V_{\mathrm{gd,inr,ac}} + \mathbf{CINR} \cdot V_{\mathrm{gs,inr,ac}}) \tag{4.320}$$

$$Q_{\mathrm{s,inr}} = \mathbf{CINR} \cdot (V_{\mathrm{sg,inr,ac}} - \Delta V_{\mathrm{inr}}) \tag{4.321}$$

$$Q_{\mathrm{d,inr}} = \mathbf{CINRD} \cdot (V_{\mathrm{dg,inr,ac}} - \Delta V_{\mathrm{inr}}) \tag{4.322}$$

Total intrinsic charges:

$$Q^{(i)}_{\mathrm{G}} = {Q'}^{(i)}_{\mathrm{G}} + Q_{\mathrm{g,inr}} \tag{4.323}$$

$$Q^{(i)}_{\mathrm{I}} = {Q'}^{(i)}_{\mathrm{I}} + Q_{\mathrm{d,inr}} + Q_{\mathrm{s,inr}} \tag{4.324}$$

$$Q^{(i)}_{\mathrm{D}} = {Q'}^{(i)}_{\mathrm{D}} + Q_{\mathrm{d,inr}} \tag{4.325}$$

$$Q^{(i)}_{\mathrm{S}} = Q^{(i)}_{\mathrm{I}} - Q^{(i)}_{\mathrm{D}} \tag{4.326}$$

$$Q^{(i)}_{\mathrm{B}} = -Q^{(i)}_{\mathrm{I}} - Q^{(i)}_{\mathrm{G}} \tag{4.327}$$

4.3.4 Extrinsic Charge Model

The charges of the source and drain overlap regions:

$$Q_{\mathrm{sov}} = \mathbf{CGOV} \cdot (V_{\mathrm{GS}} - \psi_{\mathrm{sov}}) \tag{4.328}$$

$$Q_{\mathrm{dov}} = \mathbf{CGOVD} \cdot (V_{\mathrm{GS}} - V_{\mathrm{DS}} - \psi_{\mathrm{dov}}) \tag{4.329}$$

$$x_{\mathrm{gb,eff,ov}} = \ln\left(1 + \exp\left(\mathbf{CGOVACCG} \cdot \left(\frac{V_{\mathrm{GB}} - \boldsymbol{V_{\mathrm{FB}}}}{2 \cdot \phi_{\mathrm{T}}} + \boldsymbol{\Delta x_{\mathrm{gb,ov}}}\right)\right)\right) \tag{4.330}$$

$$Q_{\mathrm{g,ov}} = -2 \cdot \phi_{\mathrm{T}} \cdot \mathbf{FCGOVACC} \cdot \mathbf{CGOV} \cdot \frac{x_{\mathrm{gb,eff,ov}}}{\mathbf{CGOVACCG}} \cdot \left(1 - \frac{\ln\left(1 + x_{\mathrm{gb,eff,ov}}\right)}{2 + x_{\mathrm{gb,eff,ov}}}\right) \tag{4.331}$$

$$x_{\mathrm{gb,eff,dov}} = \ln\left(1 + \exp\left(\mathbf{CGOVACCG} \cdot \left(\frac{V_{\mathrm{GB}} - \boldsymbol{V_{\mathrm{FB}}}}{2 \cdot \phi_{\mathrm{T}}} + \boldsymbol{\Delta x_{\mathrm{gb,dov}}}\right)\right)\right) \tag{4.332}$$

$$Q_{\mathrm{g,dov}} = -2 \cdot \phi_{\mathrm{T}} \cdot \mathbf{FCGOVACC} \cdot \mathbf{CGOVD} \cdot \frac{x_{\mathrm{gb,eff,dov}}}{\mathbf{CGOVACCG}} \cdot \left(1 - \frac{\ln\left(1 + x_{\mathrm{gb,eff,dov}}\right)}{2 + x_{\mathrm{gb,eff,dov}}}\right) \tag{4.333}$$

$$y_{\mathrm{b,ov}} = \exp\left(\frac{V_{\mathrm{GB}} - \boldsymbol{V_{\mathrm{FB}}}}{2 \cdot \phi_{\mathrm{T}}} + \boldsymbol{\Delta x_{\mathrm{gb,ov}}}\right) \tag{4.334}$$

$$Q_{\mathrm{g,ov}} = -2 \cdot \mathbf{FCGOVACC} \cdot \mathbf{CGOV} \cdot \phi_{\mathrm{T}} \cdot \ln\left(1 + y_{\mathrm{b,ov}}\right) \cdot \left(1 - \frac{\ln\left(1 + \ln\left(1 + y_{\mathrm{b,ov}}\right)\right)}{2 + \ln\left(1 + y_{\mathrm{b,ov}}\right)}\right) \tag{4.335}$$

The charge of the bulk overlap region

$$Q_{\mathrm{bov}} = \mathbf{CGBOV} \cdot V_{\mathrm{GB}} + Q_{\mathrm{g,ov}} + Q_{\mathrm{g,dov}} \tag{4.336}$$

Outer fringe charge:

$$Q_{\mathrm{ofs}} = \mathbf{CFR} \cdot V_{\mathrm{GS}} \tag{4.337}$$

$$Q_{\mathrm{ofd}} = \mathbf{CFRD} \cdot (V_{\mathrm{GS}} - V_{\mathrm{DS}}) \tag{4.338}$$

4.3.5 Total Terminal Charges

$$Q_{\mathrm{G}} = Q_{\mathrm{G}}^{(i)} + Q_{\mathrm{sov}} + Q_{\mathrm{dov}} + Q_{\mathrm{ofs}} + Q_{\mathrm{ofd}} + Q_{\mathrm{bov}} \tag{4.339}$$

$$Q_{\mathrm{S}} = Q_{\mathrm{S}}^{(i)} - Q_{\mathrm{sov}} - Q_{\mathrm{ofs}} \tag{4.340}$$

$$Q_{\mathrm{D}} = Q_{\mathrm{D}}^{(i)} - Q_{\mathrm{dov}} - Q_{\mathrm{ofd}} \tag{4.341}$$

$$Q_{\mathrm{B}} = Q_{\mathrm{B}}^{(i)} - Q_{\mathrm{bov}} \tag{4.342}$$

4.4 Noise Model

Eqs. (4.378)-(4.368) are only calculated for $x_{\mathrm{g,dc}} > 0$. In these equations f_{op} represents the operation frequency of the transistor and $j = \sqrt{-1}$.

4.4.1 Flicker noise

$$N^* = \frac{C_{\mathrm{ox}}}{q} \cdot \alpha_{\mathrm{m,dc}} \cdot \phi_{\mathrm{T,dc}} \tag{4.343}$$

$$N^*_{\mathrm{m}} = \frac{C_{\mathrm{ox}}}{q} \cdot q^*_{\mathrm{im,dc}} \tag{4.344}$$

$$\Delta N = \frac{C_{\mathrm{ox}}}{q} \cdot \alpha_{\mathrm{m,dc}} \cdot \Delta\psi_{\mathrm{dc}} \tag{4.345}$$

$$S_{\mathrm{fl}} = \frac{q \cdot \phi^2_{\mathrm{T,dc}} \cdot \boldsymbol{\beta} \cdot I_{\mathrm{DS}}}{(f_{\mathrm{op}})^{\mathbf{EF}} \cdot C_{\mathrm{ox}} \cdot G_{\mathrm{vsat,dc}} \cdot N^*} \cdot \left[(\mathbf{NFA} - \mathbf{NFB} \cdot N^* + \mathbf{NFC} \cdot N^{*\,2}) \cdot \ln\left(\frac{N^*_{\mathrm{m}} + \Delta N/2}{N^*_{\mathrm{m}} - \Delta N/2}\right) + \Big(\mathbf{NFB} + \mathbf{NFC} \cdot [N^*_{\mathrm{m}} - 2 \cdot N^*]\Big) \cdot \Delta N \right] \tag{4.346}$$

4.4.2 Thermal noise

Intrinsic thermal noise

$$H_0 = \frac{q^*_{\mathrm{im,dc}}}{\alpha_{\mathrm{m,dc}}} \tag{4.347}$$

$$t_1 = \frac{q_{\mathrm{im,dc}}}{q^*_{\mathrm{im,dc}}} \tag{4.348}$$

$$t_2 = \left(\frac{\Delta\psi_{\mathrm{dc}}}{12 \cdot H_0}\right)^2 \tag{4.349}$$

$$R = \frac{H_0}{H_{\mathrm{dc}}} - 1 \tag{4.350}$$

$$l_{\mathrm{c}} = 1 - 12 \cdot t_2 \cdot R \tag{4.351}$$

$$g_{\mathrm{ideal}} = \frac{\boldsymbol{\beta} \cdot q^*_{\mathrm{im,dc}}}{G_{\mathrm{vsat,dc}}} \tag{4.352}$$

$$C_{\mathrm{Geff}} = \left(\frac{G_{\mathrm{vsat,ac}}}{G_{\mathrm{mob,ac}} \cdot G_{\Delta L_{\mathrm{ac}}}}\right)^2 \cdot C^{\mathrm{qm}}_{\mathrm{OX}} \cdot \eta_{\mathrm{p,ac}} \tag{4.353}$$

$$m_{\mathrm{id,int}} = \frac{g_{\mathrm{ideal}}}{l^2_{\mathrm{c}}} \cdot [t_1 + 12 \cdot t_2 - 24 \cdot (1 + t_1) \cdot t_2 \cdot R] \tag{4.354}$$

$$m_{\text{ig,int}} = \frac{1}{l_c^2 \cdot g_{\text{ideal}}} \cdot \left[\frac{t_1}{12} - t_2 \cdot \left(t_1 + \frac{1}{5} - 12 \cdot t_2\right) - \frac{8}{5} \cdot t_2 \cdot (t_1 + 1 - 12 \cdot t_2) \cdot R\right] \tag{4.355}$$

$$m_{\text{igid,int}} = \frac{\sqrt{t_2}}{l_c^2} \cdot \left[1 - 12 \cdot t_2 - \left(t_1 + \frac{96}{5} \cdot t_2 - 12 \cdot t_1 \cdot t_2\right) \cdot R\right] \tag{4.356}$$

Excess thermal noise

For short (sub-100-nm) devices, it has been shown that the conventional local source for thermal noise gets a field dependent extra term [7, 8] and changes from

$$\langle i_n^2 \rangle = 4 \cdot k \cdot T \cdot g$$

to

$$\langle i_n^2 \rangle = 4 \cdot k \cdot T \cdot g \cdot \left[1 + 3 \cdot \frac{(q \cdot E \cdot \tau)^2}{m^* \cdot k \cdot T}\right] = 4 \cdot k \cdot T \cdot g + 12 \cdot g \cdot m^* \cdot \mu^2 \cdot E^2.$$

Here, g denotes the local channel conductance. Integration along the channel (following the improved Klaassen-Prins method) leads to expressions for the drain-current noise, induced gate noise, and correlation.

Excess thermal noise equations:

$$z_{\text{sat,exc}} = \begin{cases} \left(\theta'_{\text{sat,dc}} \cdot \Delta\psi_{\text{dc}}\right)^2 & \text{for NMOS} \\ \dfrac{\left(\theta'_{\text{sat,dc}} \cdot \Delta\psi_{\text{dc}}\right)^2}{1 + \theta'_{\text{sat,dc}} \cdot \Delta\psi_{\text{dc}}} & \text{for PMOS} \end{cases} \tag{4.357}$$

$$G_{\text{vsat,exc}} = \frac{G_{\text{mob,dc}}}{2} \cdot \left(1 + \sqrt{1 + 2 \cdot z_{\text{sat,exc}}}\right) \tag{4.358}$$

$$g_{\text{fac}} = \frac{G_{\text{mob,dc}}}{G_{\text{vsat,exc}} \cdot l_c} \tag{4.359}$$

$$m_{\text{id,exc}} = \frac{\textbf{FNTEXC} \cdot m_0}{4 \cdot k_B \cdot T_{\text{KD}}} \cdot g_{\text{fac}}^2 \cdot I_{\text{DS}} \cdot V_{\text{dse,dc}} \tag{4.360}$$

$$m_{\text{ig,exc}} = m_{\text{id,exc}} \cdot \frac{1 + 12 \cdot t_2}{12 \cdot g_{\text{ideal}}^2} \tag{4.361}$$

$$m_{\text{igid,exc}} = -m_{\text{id,exc}} \cdot \frac{\sqrt{t_2} \cdot (1 + R)}{g_{\text{ideal}}} \tag{4.362}$$

Total thermal noise

$$m_{\text{id}} = m_{\text{id,int}} + m_{\text{id,exc}} \tag{4.363}$$

$$m_{\text{ig}} = m_{\text{ig,int}} + m_{\text{ig,exc}} \tag{4.364}$$

$$m_{\text{igid}} = m_{\text{igid,int}} + m_{\text{igid,exc}} \tag{4.365}$$

$$S_{\text{id}} = \boldsymbol{N_T} \cdot m_{\text{id}} \tag{4.366}$$

$$S_{\text{ig}} = \boldsymbol{N_T} \cdot \frac{(2 \cdot \pi \cdot f_{\text{op}} \cdot C_{\text{Geff}})^2 \cdot m_{\text{ig}}}{1 + (2 \cdot \pi \cdot f_{\text{op}} \cdot C_{\text{Geff}} \cdot m_{\text{ig}})^2} \tag{4.367}$$

$$S_{\text{igid}} = \boldsymbol{N_T} \cdot \frac{2 \cdot \pi \cdot j \cdot f_{\text{op}} \cdot C_{\text{Geff}} \cdot m_{\text{igid}}}{1 + 2 \cdot \pi \cdot j \cdot f_{\text{op}} \cdot C_{\text{Geff}} \cdot m_{\text{ig}}} \tag{4.368}$$

Thermal noise for parasitic resistances (see Fig. 3.2)

$$S_{\mathrm{R_G}} = 4 \cdot k_{\mathrm{B}} \cdot T_{\mathrm{KD}} / R_{\mathrm{gate}} \tag{4.369}$$

$$S_{\mathrm{R_{BULK}}} = 4 \cdot k_{\mathrm{B}} \cdot T_{\mathrm{KD}} / R_{\mathrm{bulk}} \tag{4.370}$$

$$S_{\mathrm{R_{WELL}}} = 4 \cdot k_{\mathrm{B}} \cdot T_{\mathrm{KD}} / R_{\mathrm{well}} \tag{4.371}$$

$$S_{\mathrm{R_{JUNS}}} = 4 \cdot k_{\mathrm{B}} \cdot T_{\mathrm{KD}} / R_{\mathrm{juns}} \tag{4.372}$$

$$S_{\mathrm{R_{JUND}}} = 4 \cdot k_{\mathrm{B}} \cdot T_{\mathrm{KD}} / R_{\mathrm{jund}} \tag{4.373}$$

4.4.3 Shot noise

Gate current shot noise:

$$S_{\mathrm{igs}} = 2 \cdot q \cdot (I_{\mathrm{GCS}} + I_{\mathrm{GSov}}) \tag{4.374}$$

$$S_{\mathrm{igd}} = 2 \cdot q \cdot (I_{\mathrm{GCD}} + I_{\mathrm{GDov}}) \tag{4.375}$$

Avalanche current shot noise:

$$S_{\mathrm{avl}} = 2 \cdot q \cdot (1 + M_{\mathrm{avl}}) \cdot I_{\mathrm{avl}} \tag{4.376}$$

4.4.4 Edge transistor noise

The equations in this Section are only calculated when **SWEDGE** $= 1$ and **BETNEDGE** > 0 and $x_{\mathrm{g,edge}} > 0$. Flicker noise:

$$\alpha_{\mathrm{noise,edge}} = \frac{\sqrt{\frac{4}{\boldsymbol{G_{\mathrm{edge}}}^2} \cdot (x_{\mathrm{g,edge}} - q_{\mathrm{ieff,edge,m}}) + 1}}{\sqrt{\frac{4}{\boldsymbol{G_{\mathrm{edge}}}^2} \cdot (x_{\mathrm{g,edge}} - q_{\mathrm{ieff,edge,m}}) + 1.1} - 1} \tag{4.377}$$

$$N^*_{\mathrm{edge}} = \frac{C_{\mathrm{ox}}}{q} \cdot \boldsymbol{\phi_{\mathrm{T}}} \cdot \alpha_{\mathrm{noise,edge}} \tag{4.378}$$

$$N^*_{\mathrm{m,edge}} = \frac{C_{\mathrm{ox}}}{q} \cdot \boldsymbol{\phi_{\mathrm{T}}} \cdot (q_{\mathrm{ieff,edge,m}} + \alpha_{\mathrm{noise,edge}}) \tag{4.379}$$

$$\Delta N_{\mathrm{edge}} = -\frac{C_{\mathrm{ox}}}{q} \cdot \boldsymbol{\phi_{\mathrm{T}}} \cdot \alpha_{\mathrm{noise,edge}} \cdot \alpha_{\mathrm{mb,edge}} \cdot q_{\mathrm{ieff,edge,ds}} \tag{4.380}$$

$$\begin{aligned} S_{\mathrm{fl,edge}} = \frac{q \cdot \boldsymbol{\phi_{\mathrm{T}}^2} \cdot \boldsymbol{\beta_{\mathrm{edge}}} \cdot I_{\mathrm{DSedge}}}{(f_{\mathrm{op}})^{\mathbf{EFEDGE}} \cdot C_{\mathrm{ox}} \cdot G_{\mathrm{vsat,dc}} \cdot N^*_{\mathrm{edge}}} \cdot \Bigg[& (\mathbf{NFAEDGE} - \mathbf{NFBEDGE} \cdot N^*_{\mathrm{edge}} \\ & + \mathbf{NFCEDGE} \cdot N^{*2}_{\mathrm{edge}}) \cdot \ln\left(\frac{N^*_{\mathrm{m,edge}} + \Delta N_{\mathrm{edge}}/2}{N^*_{\mathrm{m,edge}} - \Delta N_{\mathrm{edge}}/2}\right) \\ & + \Big(\mathbf{NFBEDGE} + \mathbf{NFCEDGE} \cdot [N^*_{\mathrm{m,edge}} - 2 \cdot N^*_{\mathrm{edge}}]\Big) \cdot \Delta N_{\mathrm{edge}} \Bigg] \end{aligned} \tag{4.381}$$

Thermal noise:

$$H_{0,\mathrm{edge}} = \boldsymbol{\phi}_{\mathbf{T}} \cdot \left(\frac{q_{\mathrm{ieff,edge,m}}}{\alpha_{\mathrm{noise,edge}}} + 1 \right) \tag{4.382}$$

$$t_{1,\mathrm{edge}} = \frac{\phi^{*}_{\mathrm{T,dc}}}{\boldsymbol{\phi}_{\mathbf{T}}} \cdot \frac{q_{\mathrm{ieff,edge,m}}}{q_{\mathrm{ieff,edge,m}} + \alpha_{\mathrm{noise,edge}}} \tag{4.383}$$

$$t_{2,\mathrm{edge}} = \left(\frac{\boldsymbol{\phi}_{\mathbf{T}} \cdot \alpha_{\mathrm{mb,edge}} \cdot q_{\mathrm{ieff,edge,ds}}}{12 \cdot H_{0,\mathrm{edge}}} \right)^2 \tag{4.384}$$

$$R_{\mathrm{edge}} = \frac{\alpha_{\mathrm{noise,edge}} \cdot H_{0,\mathrm{edge}}}{\alpha_{\mathrm{m}} \cdot H} - 1 \tag{4.385}$$

$$l_{\mathrm{c,edge}} = 1 - 12 \cdot t_{2,\mathrm{edge}} \cdot R_{\mathrm{edge}} \tag{4.386}$$

$$g_{\mathrm{ideal,edge}} = \frac{\boldsymbol{\beta}_{\mathbf{edge}} \cdot \boldsymbol{\phi}_{\mathbf{T}} \cdot (q_{\mathrm{ieff,edge,m}} + \alpha_{\mathrm{noise,edge}})}{G_{\mathrm{vsat,dc}}} \tag{4.387}$$

$$m_{\mathrm{id,edge}} = \frac{g_{\mathrm{ideal,edge}}}{l^2_{\mathrm{c,edge}}} \cdot \left[t_{1,\mathrm{edge}} + 12 \cdot t_{2,\mathrm{edge}} - 24 \cdot (1 + t_{1,\mathrm{edge}}) \cdot t_{2,\mathrm{edge}} \cdot R_{\mathrm{edge}} \right] \tag{4.388}$$

$$S_{\mathrm{id,dge}} = \boldsymbol{N}_{\mathbf{T,edge}} \cdot m_{\mathrm{id,edge}} \tag{4.389}$$

4.5 Self heating

Fig. 4.1 shows the simple thermal network that is implemented in PSP. The current that reflects the power dissipation is given by

$$P_{\mathrm{diss}} = I_{\mathrm{DS}} \cdot V_{\mathrm{DS}} + I_{\mathrm{impact}} \cdot (V_{\mathrm{DS}} + V_{\mathrm{SB}}) + \frac{V_{\mathrm{SIS}}^2}{R_{\mathrm{source}}} + \frac{V_{\mathrm{DID}}^2}{R_{\mathrm{drain}}}. \tag{4.390}$$

If **RTH** $< 10^{-3}$, $P_{\mathrm{diss}} = 0$. This can be used to switch off self heating.

The built-in thermal network of PSP can be bypassed (e.g., to replace it with an externally connected thermal network) by setting **CTH** $= 0$ and assigning a very large value to **RTH**.

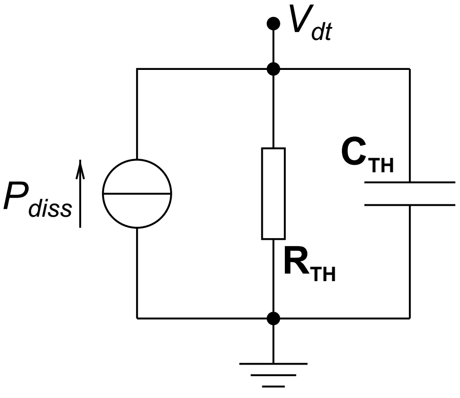

Figure 4.1: Internal thermal network of PSP

Section 5

Non-quasi-static RF model

5.1 Introduction

For high-frequency modeling and fast transient simulations, a special version of the PSP model is available, which enables the simulation of non-quasi-static (NQS) effects, and includes several parasitic resistances.

5.2 NQS-effects

In the PSP-NQS model, NQS-effects are introduced by applying the one-dimensional current continuity equation ($\partial I/\partial y \propto -\partial \rho/\partial t$) to the channel. A full numerical solution of this equation is too inefficient for compact modeling, therefore an approximate technique is used. The channel is partitioned into $N+1$ sections of equal length by assigning N equidistant *collocation points*. The charge density (per unit channel area) along the channel is then approximated by a cubic spline through these collocation points, assuring that both the charge and its first and second spatial derivatives are continuous along the channel. Within this approximation, the current continuity equation reduces to a system of N coupled first order ordinary differential equations, from which the channel charge at each collocation point can be found:

$$\left\{ \begin{array}{rcl} \dfrac{\mathrm{d}Q_1}{\mathrm{d}t} & = & f_1(Q_1, \ldots, Q_N) \\ \vdots & & \vdots \\ \dfrac{\mathrm{d}Q_N}{\mathrm{d}t} & = & f_N(Q_1, \ldots, Q_N) \end{array} \right. \tag{5.1}$$

Here, Q_i is the charge density at the i-th collocation point and f_i are functions, which contain the *complete* PSP-charge model. These equations are implemented by the definition of appropriate subcircuits (see left part of Fig. 5.1) and solved by the circuit simulator. Finally, the four terminal charges are calculated from the channel charges, using the Ward-Dutton partitioning scheme for the source and drain charges.

A full description of the PSP-NQS model is given in Section 5.3. More background information can be found in literature [9, 10].

5.3 NQS Model Equations

In this section, several symbols and notations are used which were defined in Section 4. Moreover, y denotes the (normalized) position along the channel ($y = 0$ is source side, $y = 1$ is drain side), while x denotes the surface potential (normalized to $\phi^*_{\mathrm{T,ac}}$) at a certain position.

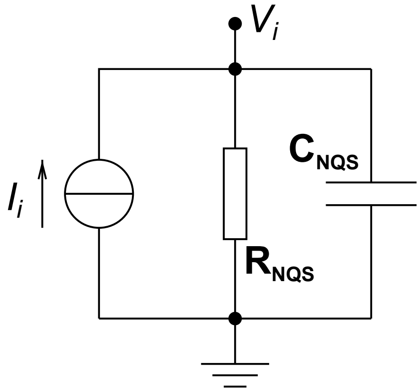

Figure 5.1: The subcircuit used to solve one of the differential equations of Eq. (5.1). The current is set to $I_i = C_{\mathrm{NQS}} \cdot f(V_1, \ldots, V_N)$, where the voltage V_i represents the charge density Q_i at the i-th collocation point and is solved by the circuit simulator. N of these circuits are defined and they are coupled through the dependence of I_i on the voltages of the other circuits. The resistance R_{NQS} has a very large value and is present only for convergence purposes. *Right:* The full network of parasitic elements in the PSP-NQS model. The large full dots indicate the five additional internal nodes.

5.3.1 Internal constants

Eqs. (5.2)–(5.7) are independent of bias conditions and time. Consequently, they have to be computed only once.

Note: In PSP only **SWNQS** $= 0, 1, 2, 3, 5, 9$ are allowed!

$$n = \textbf{SWNQS} + 1 \tag{5.2}$$

$$h = 1/n \tag{5.3}$$

The matrix A is a square $(n+1) \times (n+1)$-matrix with elements $A_{i,j}$ $(0 \le i, j \le n)$, which are used in Eq. 5.25. They are computed using the following algorithm (adapted from [11]):

1. Initial values:

$$A_{i,j} = 0 \qquad \text{for } 0 \le i, j \le n \tag{5.4}$$

$$v_i = 0 \qquad \text{for } 0 \le i \le n \tag{5.5}$$

2. First loop:

$$\left.\begin{aligned} & p = 2 + v_{i-1}/2 \\ & v_i = -1/(2 \cdot p) \\ & A_{i,i-1} = 1/h \\ & A_{i,i} = -2/h \\ & A_{i,i+1} = 1/h \\ & \left. A_{i,j} = \frac{1}{p} \cdot (3 \cdot A_{i,j}/h - A_{i-1,j}/2) \right\} \text{for } j = 0 \ldots n \end{aligned}\right\} \text{for } i = 1 \ldots (n-1) \tag{5.6}$$

3. Second loop (back substitution):

$$\left.A_{i,j} = v_i \cdot A_{i+1,j} + A_{i,j} \qquad \text{for } j = 0 \ldots n\right\} \text{for } i = (n-1) \ldots 0 \tag{5.7}$$

5.3.2 Position independent quantities

The following quantities depend on the bias conditions, but are constant along the channel:

$$\text{if } x_{\text{g,ac}} > 0 \begin{cases} y_{\text{m}} = \dfrac{1}{2} \cdot \left(1 + \dfrac{\Delta\psi_{\text{ac}}}{4 \cdot H_{\text{ac}}}\right) \\ p_{\text{d}} = \dfrac{x_{\text{gm,ac}}}{x_{\text{g,ac}} - x_{\text{m,ac}}} \\ G_{\text{p}} = G_{\text{ac}}/p_{\text{d}} \end{cases} \tag{5.8}$$

$$\text{if } x_{\text{g,ac}} \le 0 \begin{cases} y_{\text{m}} = 1/2 \\ p_{\text{d}} = 1 \\ G_{\text{p}} = G_{\text{ac}} \end{cases} \tag{5.9}$$

$$a_{\text{p}} = 1 + G_{\text{p}}/\sqrt{2} \tag{5.10}$$

$$p_{\text{mrg}} = 10^{-5} \cdot a_{\text{p}} \tag{5.11}$$

5.3.3 Position dependent surface potential and charge

Interpolated (quasi-static) surface potential along the channel:

$$\Psi(y) = x_{\text{m,ac}} + \frac{H_{\text{ac}}}{\phi^*_{\text{T,ac}}} \cdot \left(1 - \sqrt{1 - \frac{2 \cdot \Delta\psi_{\text{ac}}}{H_{\text{ac}}} \cdot (y - y_{\text{m}})}\right) \tag{5.12}$$

Normalized bulk-charge and its first two derivatives as functions of surface potential:

$$q_{\text{b}}(x) = -\text{sgn}(x) \cdot G_{\text{p}} \cdot \sqrt{\exp(-x) + x - 1} \tag{5.13}$$

$$q'_{\text{b}}(x) = \frac{G_{\text{p}}^2 \cdot [1 - \exp(-x)]}{2 \cdot q_{\text{b}}(x)} \tag{5.14}$$

$$q''_{\text{b}}(x) = -q'_{\text{b}}(x) - \frac{q'_{\text{b}}(x)^2 - G_{\text{p}}^2/2}{q_{\text{b}}(x)} \tag{5.15}$$

Surface potential as a function of normalized inversion charge (note that these equations are identical to

Eq. (4.228), despite the different notation and physical background):

$$\Pi(x_\mathrm{g}) = \begin{cases} \text{if } x_\mathrm{g} < -p_\mathrm{mrg} & \begin{cases} y_\mathrm{g} = -x_\mathrm{g} \\ z = 1.25 \cdot y_\mathrm{g}/a_\mathrm{p} \\ \eta = \left[z + 10 - \sqrt{(z-6)^2 + 64}\right]/2 \\ a = \left(y_\mathrm{g} - \eta\right)^2 + G_\mathrm{p}^2 \cdot (\eta + 1) \\ c = 2 \cdot (y_\mathrm{g} - \eta) - G_\mathrm{p}^2 \\ \tau = -\eta + \ln\left(a/G_\mathrm{p}^2\right) \\ y_0 = \sigma_1(a,\, c,\, \tau,\, \eta) \\ \Delta_0 = \exp(y_0) \\ \xi = 1 - G_\mathrm{p}^2 \cdot \Delta_0/2 \\ p = 2 \cdot (y_\mathrm{g} - y_0) + G_\mathrm{p}^2 \cdot (\Delta_0 - 1) \\ q = \left(y_\mathrm{g} - y_0\right)^2 + G_\mathrm{p}^2 \cdot (y_0 - \Delta_0 + 1) \\ \Pi = -y_0 - \dfrac{2 \cdot q}{p + \sqrt{p^2 - 4 \cdot q \cdot \xi}} \end{cases} \\ \text{if } |x_\mathrm{g}| \leq p_\mathrm{mrg} & \begin{cases} \Pi = \dfrac{x_\mathrm{g}}{a_\mathrm{p}} \end{cases} \\ \text{if } x_\mathrm{g} > p_\mathrm{mrg} & \begin{cases} \hat{x}_\mathrm{g1} = \boldsymbol{x_1} + G_\mathrm{p} \cdot \sqrt{\exp(-\boldsymbol{x_1}) + \boldsymbol{x_1} - 1} \\ \bar{x} = \dfrac{x_\mathrm{g}}{a_\mathrm{p}} \cdot \left[1 + x_\mathrm{g} \cdot (\boldsymbol{x_1} \cdot a_\mathrm{p}/\hat{x}_\mathrm{g1} - 1)/\hat{x}_\mathrm{g1}\right] \\ x_0 = x_\mathrm{g} + G_\mathrm{p}^2/2 - G_\mathrm{p} \cdot \sqrt{x_\mathrm{g} + G_\mathrm{p}^2/4 - 1 + \exp(-\bar{x})} \\ \Delta_0 = \exp(-x_0) \\ \xi = 1 - G_\mathrm{p}^2 \cdot \Delta_0/2 \\ p = 2 \cdot (x_\mathrm{g} - x_0) + G_\mathrm{p}^2 \cdot (1 - \Delta_0) \\ q = (x_\mathrm{g} - x_0)^2 - G_\mathrm{p}^2 \cdot (x_0 + \Delta_0 - 1) \\ \Pi = x_0 + \dfrac{2 \cdot q}{p + \sqrt{p^2 - 4 \cdot q \cdot \xi}} \end{cases} \end{cases} \tag{5.16}$$

$$X(x_\mathrm{g}, q_\mathrm{inv}) = \Pi(x_\mathrm{g} + q_\mathrm{inv}/p_\mathrm{d}) \tag{5.17}$$

Auxiliary functions:

$$q(x) = -p_\mathrm{d} \cdot (x_\mathrm{g} - x) - q_\mathrm{b}(x) \tag{5.18}$$

$$\psi(q, q_{x1}) = \frac{q}{q_{x1}} - 1 \tag{5.19}$$

$$\phi(q, q_{x1}, q_{x2}) = \left(1 - \frac{q \cdot q_{x2}}{q_{x1}^2}\right)/q_{x1} \tag{5.20}$$

Normalized right-hand-side of continuity equation:

$$f(x_\mathrm{g}, q, q', q'') = \begin{cases} x_\mathrm{z} = X(x_\mathrm{g}, q) \\ q_{x1} = \dfrac{\partial q}{\partial x}(x_\mathrm{z}) = p_\mathrm{d} - q'_\mathrm{b}(x_\mathrm{z}) \\ q_{x2} = \dfrac{\partial^2 q}{\partial x^2}(x_\mathrm{z}) = q''_\mathrm{b}(x_\mathrm{z}) \\ f_0 = \psi(q, q_{x1}) \cdot q'' + \phi(q, q_{x1}, q_{x2}) \cdot q'^2 \\ x_{y1} = \dfrac{\partial x_\mathrm{z}}{\partial y} = q'/q_{x1} \\ z_\mathrm{sat} = \begin{cases} \left(\theta^*_\mathrm{sat,ac} \cdot \phi^*_\mathrm{T,acf} \cdot x_{y1}\right)^2 & \text{for NMOS} \\ \dfrac{\left(\theta^*_\mathrm{sat,ac} \cdot \phi^*_\mathrm{T,ac} \cdot x_{y1}\right)^2}{1 + \theta^*_\mathrm{sat,ac} \cdot \Delta\psi_\mathrm{ac}} & \text{for PMOS} \end{cases} \\ \zeta = \sqrt{1 + 2 \cdot z_\mathrm{sat}} \\ F_\mathrm{vsat} = 2/(1 + \zeta) \\ f = F_\mathrm{vsat} \cdot \left[f_0 - F_\mathrm{vsat} \cdot \dfrac{z_\mathrm{sat}}{\zeta} \cdot \psi(q, q_{x1}) \cdot (q'' + x_{y1}^2 \cdot q''_\mathrm{b}(x_\mathrm{z}))\right] \end{cases} \tag{5.21}$$

Normalization constant:

$$T_\mathrm{norm} = \frac{\mathbf{MUNQS} \cdot \phi^*_\mathrm{T,ac} \cdot \boldsymbol{\beta}}{C_\mathrm{OX}^\mathrm{qm}} \cdot G_\mathrm{mob,ac} \cdot G_{\Delta L,\mathrm{ac}} \tag{5.22}$$

5.3.4 Cubic spline interpolation

Using cubic spline interpolation, the spatial derivatives $\frac{\partial q_i}{\partial y}(t)$ and $\frac{\partial^2 q_i}{\partial y^2}(t)$ can be expressed as functions of the $q_i(t)$.

$$q''_0 = 0 \tag{5.23}$$

$$q''_n = 0 \tag{5.24}$$

$$q''_i = \sum_{j=0}^{n} A_{i,j} \cdot q_i \qquad \text{for } 1 \leq i \leq n-1 \tag{5.25}$$

$$q'_i = \frac{q_{i+1} - q_i}{h} - \frac{h}{6} \cdot (2 \cdot q''_i + q''_{i+1}) \qquad \text{for } 1 \leq i \leq n-1 \tag{5.26}$$

5.3.5 Continuity equation

Initial value for the q_i ($0 \leq i \leq n$). These values are used for the DC operating point.

$$x_{i,0} = \Psi(i \cdot h) \tag{5.27}$$

$$q_{i,0} = q(x_{i,0}) \tag{5.28}$$

Note: $x_{0,0} = x_\mathrm{s}$ and $x_{n,0} = x_\mathrm{d}$. Moreover, these values coincide with those in the quasi-static part of PSP.

The core of the NQS-model is the solution of $q(y,t)$ from the charge continuity equation along the channel. By approximating the y-dependence by a cubic spline through a number of collocation points, the problem is reduced to solving the $q_i(t)$ from the following set of coupled differential equations.

$$\boxed{\begin{cases} \dfrac{\partial q_i}{\partial t}(t) + T_\mathrm{norm} \cdot f\left(x_\mathrm{g,ac},\, q_i(t),\, \dfrac{\partial q_i}{\partial y}(t),\, \dfrac{\partial^2 q_i}{\partial y^2}(t)\right) = 0 \\ \\ q_i(0) = q_{i,0} \end{cases} \qquad \text{for } 1 \le i \le n-1} \tag{5.29}$$

Note that the boundary points $q_0(t) = q(x_\mathrm{s}) = q_\mathrm{is}$ and $q_n(t) = q(x_\mathrm{d}) = q_\mathrm{id}$ remain fixed to their quasi-static values; they are not solved from the equation above.

The set of differential equations defined above is solved by the circuit simulator via the subcircuits shown in the left part of Fig. 5.1.

5.3.6 Non-quasi-static terminal charges

Once the q_i are known, the NQS terminal charges can be computed:

$$S_0 = \sum_{i=1}^{n-1} q_i \tag{5.30}$$

$$S_2 = \sum_{i=1}^{n-1} q_i'' \tag{5.31}$$

$$q_\mathrm{I}^\mathrm{NQS} = \int_0^1 q(y)\,\mathrm{d}y = h \cdot S_0 + \frac{h}{2} \cdot (u_0 + u_n) - \frac{h^3}{12} \cdot S_2 \tag{5.32}$$

$$U_0 = \sum_{i=1}^{n-1} i \cdot q_i \tag{5.33}$$

$$U_2 = \sum_{i=1}^{n-1} i \cdot q_i'' \tag{5.34}$$

$$q_\mathrm{D}^\mathrm{NQS} = \int_0^1 y \cdot q(y)\,\mathrm{d}y = h^2 \cdot U_0 + \frac{h^2}{6} \cdot [q_0 + (3n-1)u_n] - \frac{h^4}{12} \cdot U_2 \tag{5.35}$$

$$q_\mathrm{S}^\mathrm{NQS} = q_\mathrm{I}^\mathrm{NQS} - q_\mathrm{D}^\mathrm{NQS} \tag{5.36}$$

Currently, only **SWNQS** $= 0, 1, 2, 3, 5, 9$ are allowed. For odd values of **SWNQS** the gate charge is integrated along the channel using “Simpson’s rule”. If **SWNQS** $= 2$, “Simpson’s $3/8$-rule” is used.

- If **SWNQS** is odd (that is, n is even):

$$q_\mathrm{G}^\mathrm{NQS} = p_\mathrm{d} \cdot \left[x_\mathrm{g,ac} - \frac{h}{3} \cdot \left(X(x_\mathrm{g,ac}, q_0) + 4 \cdot \sum_{i=1}^{n/2} X(x_\mathrm{g,ac}, q_{2i-1}) + 2 \cdot \sum_{i=1}^{n/2-1} X(x_\mathrm{g,ac}, q_{2i}) + X(x_\mathrm{g,ac}, q_n)\right)\right] \tag{5.37}$$

- If **SWNQS** $= 2$ (that is, $n = 3$):

$$q_{\mathrm{G}}^{\mathrm{NQS}} = p_{\mathrm{d}} \cdot \left[x_{\mathrm{g,ac}} - \frac{3 \cdot h}{8} \cdot \left(X(x_{\mathrm{g,ac}}, q_0) + 3 \cdot X(x_{\mathrm{g,ac}}, q_1) + 3 \cdot X(x_{\mathrm{g,ac}}, q_2) + X(x_{\mathrm{g,ac}}, q_3) \right) \right] \tag{5.38}$$

Convert back to conventional units:

$$Q_{\mathrm{S}}^{\mathrm{NQS}} = C_{\mathrm{OX}}^{\mathrm{qm}} \cdot \phi_{\mathrm{T,ac}}^{*} \cdot q_{\mathrm{S}}^{\mathrm{NQS}} \tag{5.39}$$

$$Q_{\mathrm{D}}^{\mathrm{NQS}} = C_{\mathrm{OX}}^{\mathrm{qm}} \cdot \phi_{\mathrm{T,ac}}^{*} \cdot q_{\mathrm{D}}^{\mathrm{NQS}} \tag{5.40}$$

$$Q_{\mathrm{G}}^{\mathrm{NQS}} = C_{\mathrm{OX}}^{\mathrm{qm}} \cdot \phi_{\mathrm{T,ac}}^{*} \cdot q_{\mathrm{G}}^{\mathrm{NQS}} \tag{5.41}$$

$$Q_{\mathrm{B}}^{\mathrm{NQS}} = -(Q_{\mathrm{S}}^{\mathrm{NQS}} + Q_{\mathrm{D}}^{\mathrm{NQS}} + Q_{\mathrm{G}}^{\mathrm{NQS}}) \tag{5.42}$$

Section 6

Embedding

6.1 Model selection

Circuit simulators have different ways for the user to determine which model must be used for simulation. Typically, model selection is either done by *name* or by assigning a value to the parameter **LEVEL**. The method to be used is prescribed by the circuit simulator vendor. If selection is done by name, the value of the parameter **LEVEL** is generally ignored. When Verilog-A code is used, model selection is always done by name.

For the SiMKit and the Verilog-A code provided by the PSP model developers, the method and values to be used are given in the table below. For other implementations, the method/value provided by the circuit simulator vendor is to be used.

From PSP 103.0 onwards, the global, local and binning models are unified. All three models are called by the same *name* or **LEVEL**. Model flavor selection is done by setting parameter **SWGEO**.

Simulator	Model selection by	Global + binning (geom.)	Local
Spectre	`psp104`	**SWGEO** $= 1$	**SWGEO** $= 0$
Pstar	**LEVEL** $= 104$		
ADS	`psp104`		
Verilog-A	`PSP104VA`		

6.2 Case of parameters

Throughout this document, all parameter names are printed in uppercase characters. Similarly, in the Verilog-A code provided by the PSP model developers, the parameters are in upper case characters. However, in other PSP implementations a different choice can be made. For example, the parameter names may be in lowercase characters (possibly first character capitalized) if this is conform the conventions of the circuit simulator.

6.3 Embedding PSP in a Circuit Simulator

In CMOS technologies both n- and p-channel MOS transistors are supported. It is convenient to use the same set of equations for both types of transistor instead of two separate models. This is accomplished by mapping a p-channel device with its bias conditions and parameter set onto an equivalent n-channel device with appropriately changed bias conditions (i.e. currents, voltages and charges) and parameters. In this way both types of transistor can be treated internally as an n-channel transistor. Nevertheless, the electrical behavior of electrons and holes is not exactly the same (e.g., the mobility and tunneling behavior), and consequently slightly different equations have to be used in case of n- or p-type transistors.

Designers are used to the standard terminology of source, drain, gate and bulk. Therefore, in the context of a circuit simulator it is traditionally possible to address, say, the drain of MOST number 17, even if in reality the corresponding source is at a higher potential (n-channel case). More strongly, most circuit simulators provide for model evaluation values for $V_{\rm DS}$, $V_{\rm GS}$, and $V_{\rm SB}$ based on an a priori assignment of source, drain, and bulk, independent of the actual bias conditions. Since PSP assumes that saturation occurs at the drain side of the MOSFET, the basic model cannot cope with bias conditions that correspond to $V_{\rm DS} < 0$. Again a transformation of the bias conditions is necessary. In this case, the transformation corresponds to internally reassigning source and drain, applying the standard electrical model, and then reassigning the currents and charges to the original terminals. In PSP care has been taken to preserve symmetry with respect to drain and source at $V_{\rm DS} = 0$. In other words, no singularities will occur in the higher-order derivatives at $V_{\rm DS} = 0$.

In detail, for correct embedding of PSP into a circuit simulator, the following procedure—illustrated in Fig. 6.1—is followed. It is assumed that the simulator provides the nodal potentials $V_{\rm D}^e$, $V_{\rm G}^e$, $V_{\rm S}^e$ and $V_{\rm B}^e$ based on an a priori assignment of drain, gate, source and bulk.

Step 1 The voltages $V_{\rm DS}'$, $V_{\rm GS}'$, and $V_{\rm SB}'$ are calculated from the nodal potentials provided by the circuit simulator. In the same step, the value of the parameter **TYPE** is used to deal with the polarity of the device. From here onwards, all transistors can be treated as n-channel devices.

Step 2 Depending on the sign of $V_{\rm DS}'$, 'source-drain interchange' is performed. At this level, the voltages comply to all the requirements for input quantities of PSP.

Step 3 All the internal output quantities (i.e. channel current, weak-avalanche current, gate current, nodal charges, and noise-power spectral densities) are evaluated using the standard PSP equations (Section 4) and the internal voltages.

Step 4 The internal output quantities are corrected for a possible source-drain interchange.

Step 5 External output are corrected for a possible p-channel transformation and **MULT** is applied. The quantities of the intrinsic MOSFET and the junctions are combined.

In general, separate parameter sets are used for n- and p-channel transistors, which are distinguished by the value of **TYPE**. As a consequence, the changes in the parameter values necessary for a p-channel type transistor are normally already included in the parameter sets on file. The changes should therefore not be included in the simulator.

6.3.1 Selection of device type

In the SiMKit-based and built-in version of PSP in certain circuit simulators, the selection of device type (nmos or pmos) is done using a different parameter, or using different parameter values. The correct values for some circuit simulators are given in the table below.

Simulator	Parameter	Value NMOS	value PMOS
Spectre	`type`	n	p
Pstar	`type`	1	-1
ADS	`gender`	1	0
Verilog-A	`TYPE`	1	-1

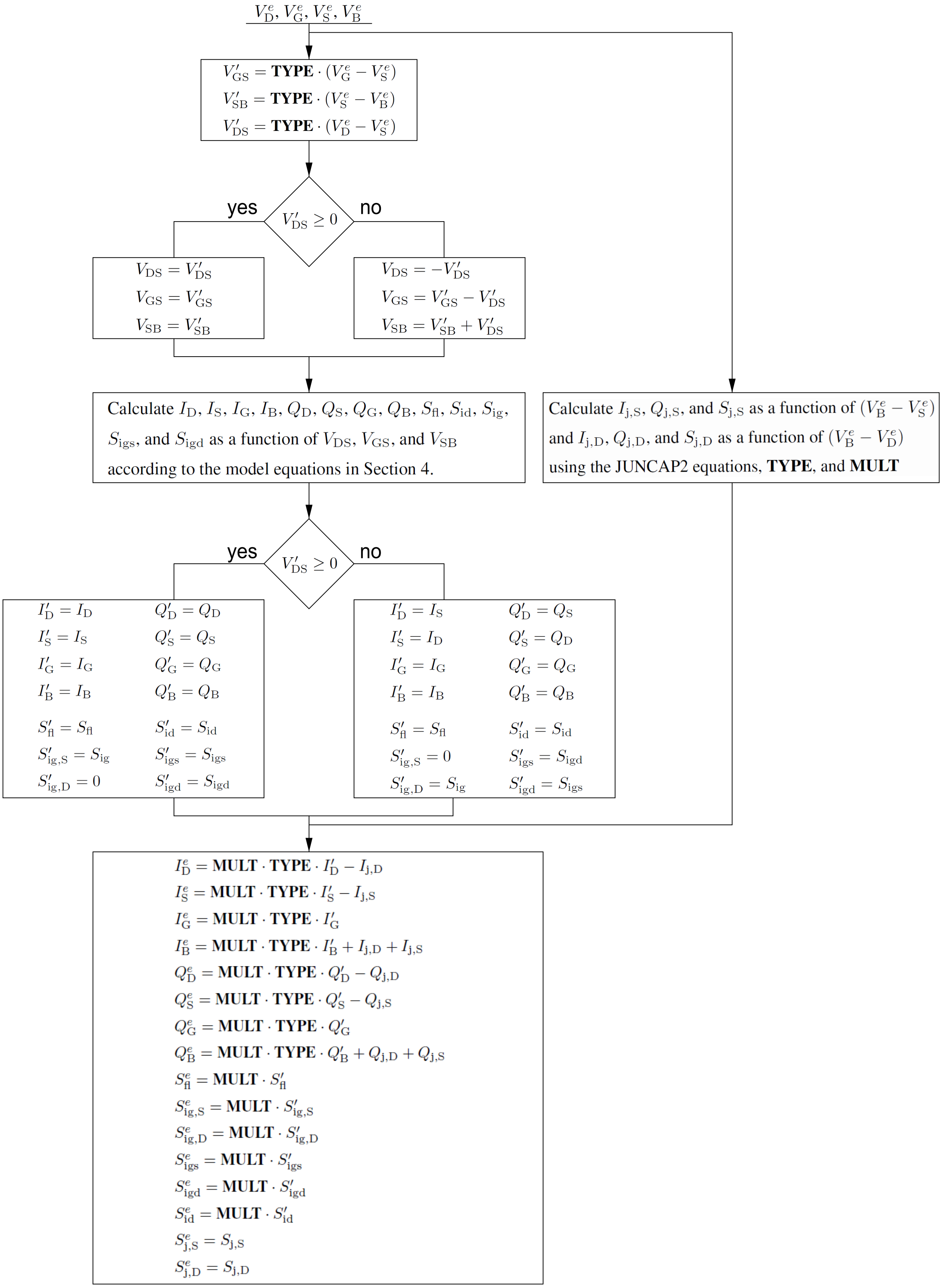

Figure 6.1: Schematic overview of source-drain interchange and handling of **TYPE** and **MULT**. Note that **TYPE** and **MULT** are included in the JUNCAP2 model equations.

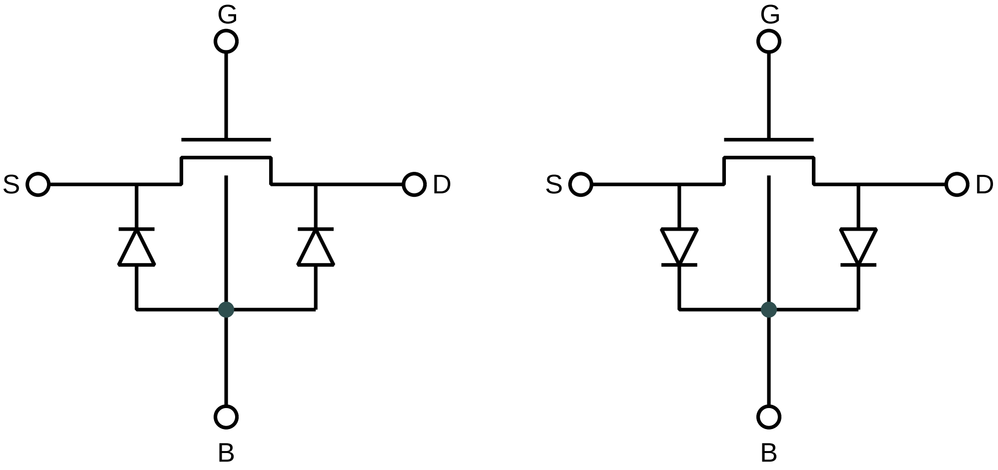

Figure 6.2: Topology of the PSP model. *Left:* n-channel MOSFET; *Right:* p-channel MOSFET. In PSP, the correct diode polarity is automatically chosen via the **TYPE**-parameter.

6.4 Integration of JUNCAP2 in PSP

Introduction

The JUNCAP2 model 200 is an integral part of PSP 104. In addition, it is available as a stand-alone model. A complete description of the JUNCAP2-model (including all model equations) can be found in the documentation of JUNCAP2's stand alone version [12]. In this section, only the integration of JUNCAP2 in PSP is described.

Topology

In a MOS transistor, there are two junctions: one between source and bulk, and one between drain and bulk. In case of an n-channel MOSFET, the junction anode corresponds to the MOSFET bulk terminal, and the junction cathodes correspond to the source and the drain. In case of a p-channel MOSFET, it is the other way around: now the junction cathode corresponds to the MOSFET bulk terminal, and the junction anodes correspond to the source and the drain. The connections are schematically given in Fig. 6.2. In PSP, this change of junction terminal connections in case of a p-MOSFET is handled automatically via the **TYPE** parameter.

In most cases, the MOSFET is operated in such a way that the junctions are either biased in the reverse mode of operation or not biased at all. In some applications, however, the source-bulk junction has a small forward bias. This is also the case in partially depleted SOI (PDSOI).

As indicated in Fig. 6.1, the interchange of source and drain for $V_{\rm DS} < 0$ (as explained above for the intrinsic MOS model) does *not* apply to the junctions. For example, **ABDRAIN** always refers to junction between the bulk and the terminal known as 'drain' to the simulator, independent of the sign of $V_{\rm DS}$.

Global and local model level

As explained in the introduction, the PSP model has a local and a global level. The JUNCAP2 model is a geometrically scaled model, i.e. it is valid for a range of junction geometries (as described by the geometrical parameters **AB**, **LS**, and **LG**). It has turned out that it is very unnatural to create a local parameter set for JUNCAP2, valid for one particular junction geometry: such a parameter set would have as many parameters as the global parameter set, and would be of no use. (Note that, in contrast, the local model for the intrinsic MOSFET is very useful in, e.g., parameter extraction; this is not the case for JUNCAP2.)

Therefore, the JUNCAP2 model is connected in exactly the same way to both the local and global model levels of PSP. That means that the resulting PSP local model is valid for a MOSFET with one particular channel width and length, but with arbitrary junction geometry.

Parameters

Both junctions in the MOSFET are modeled with the same set of JUNCAP2 parameters. In the PSP model, the geometrical parameters **AB**, **LS**, and **LG** need to be specified for both source and drain. They will be denoted as **ABSOURCE**, **LSSOURCE**, and **LGSOURCE** for the source junction, and **ABDRAIN**, **LSDRAIN**, and **LGDRAIN** for the drain junction. For compatibility with BSIM instance parameters, there is also an option to use **AS**, **AD**, **PS**, and **PD**. The complete list of instance parameters (PSP and JUNCAP2) can be found in Section 2.5.1.

The parameter **MULT** is merged with the parameter **MULT** of the intrinsic MOSFET model. In other words, both intrinsic currents, charges, and noise as well as junction currents, charges and noise are multiplied by one single parameter **MULT**. Beside **MULT**, also the parameters **DTA** and **TYPE** are shared by the intrinsic MOSFET model and the junction model. For clarity, we mention here that the reference temperatures of the intrinsic MOSFET model and junction model are *not* merged; they each have their own value and name (**TR** and **TRJ**, respectively). The currents, charges and spectral noise densities of the source and drain junctions are labeled $I_{\rm j,S}$, $Q_{\rm j,S}$, $S_{\rm j,S}$, $I_{\rm j,D}$, $Q_{\rm j,D}$, and $S_{\rm j,D}$ in Fig. 6.1.

6.5 Verilog-A versus C

As mentioned in Section 1.3, two implementations of the PSP-model are distributed: in Verilog-A language and in C-language (as part of the SiMKit). The C-version is automatically generated from the Verilog-A version by a software package called ADMS [1]. This procedure guarantees that the two implementations contain identical model equations.

Nevertheless, there are a few minor differences between the two, which are due to certain limitations of either the Verilog-A language or the circuit simulators supported in the SiMKit-framework. These differences are described below.

6.5.1 Implementation of GMIN

Onwards PSP103.8, in the Verilog-A version of PSP, $G_{\rm min}$ is controlled by the simulator using this function:

```
Gmin  =   $simparam(``gmin'',0.0);
```

In the implementation, there is an additional term in Eqs. (4.279) , (4.280) and (4.282), resulting in

$$I_{\rm D} = I_{\rm DS} + I_{\rm DS,edge} + I_{\rm avl} - I_{\rm GDov} - I_{\rm GCD} + I_{\rm gidl} + {\rm Gmin} \cdot V_{\rm DB} \tag{6.1}$$

$$I_{\rm S} = -I_{\rm DS} - I_{\rm DS,edge} - I_{\rm GSov} - I_{\rm GCS} + I_{\rm gisl} + Gmin \cdot V_{\rm SB} \tag{6.2}$$

$$I_{\rm B} = -I_{\rm avl} - I_{\rm GB} - I_{\rm gidl} - I_{\rm gisl} - Gmin \cdot V_{\rm DB} - Gmin \cdot V_{\rm SB} \tag{6.3}$$

In the SiMKit, $G_{\rm min}$ is a variable which is accessible by the circuit simulator. This allows the circuit simulator to improve the convergence properties of a circuit by making use of so-called ‘$G_{\rm min}$-stepping’.

6.5.2 Implementation of parasitic resistances

From PSP 102.2 and PSP 103.0 onwards, a network of parasitic resistors has been inserted around the intrinsic MOSFET. If the user sets one or more of these resistance values to zero, the associated internal node(s) could be shorted to one of its neighbors, reducing the size of the matrix in the circuit simulator. This phenomenon is called ‘node collapse’ and is supported by most major circuit simulators.

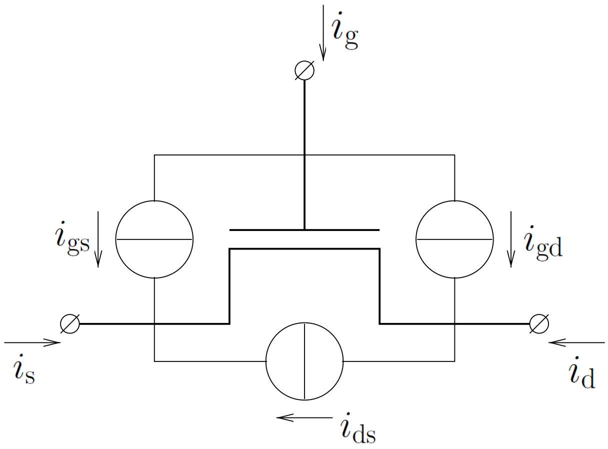

Figure 6.3: Definition of noise currents.

Flexible topology (and thus node collapse) is presently supported by most Verilog-A compilers. As a result, node collapse is functional in the official PSP Verilog-A in the majority of today's circuit simulators.

From SiMKit 3.0 onwards, the SiMKit architecture allows for flexible topologies and therefore supports node collapse in PSP. This functionality is therefore available in circuit simulations with that can work with SiMKit. Besides, many circuit simulators that have a native implementation of PSP support node collapse.

6.5.3 Implementation of the noise-equations

Definition of noise model

Eqs. (4.366), (4.367), and (4.368) describe the noise power spectral density of the thermal noise. In this section, the relationship between the quantities S_id, S_ig, and S_igid (as calculated in these equations) and noise sources in the model is defined.

Fig. 6.3 shows a schematic representation of a noiseless transistor (model) and three noise sources. The small-signal noise currents of these noise current sources are indicated by i_ds, i_gs, and i_gd. The two noise sources connected to G are fully correlated. Moreover, each of them is partly correlated with the noise source between S and D. More precisely, the noise powers and correlations associated with these sources are given by

$$\begin{array}{rcl}
\langle i_\mathrm{ds} \cdot i^*_\mathrm{ds} \rangle & = & S_\mathrm{id} \\
\langle i_\mathrm{gd} \cdot i^*_\mathrm{ds} \rangle & = & S_\mathrm{igid}/2 \\
\langle i_\mathrm{gs} \cdot i^*_\mathrm{ds} \rangle & = & S_\mathrm{igid}/2 \\
\langle i_\mathrm{gd} \cdot i^*_\mathrm{gd} \rangle & = & S_\mathrm{ig}/4 \\
\langle i_\mathrm{gs} \cdot i^*_\mathrm{gd} \rangle & = & S_\mathrm{ig}/4 \\
\langle i_\mathrm{gs} \cdot i^*_\mathrm{gs} \rangle & = & S_\mathrm{ig}/4
\end{array} \qquad (6.4)$$

The non-listed elements follow from the fact that this is a complex correlation matrix and therefore self-adjoint. This defines the noise model of PSP.

For completeness, we will give the noise correlation matrix associated with the *terminal* currents i_d, i_g and i_s, because it is closer related to the numbers that are obtained in a circuit simulation. Because $i_\mathrm{d} = i_\mathrm{ds} - i_\mathrm{gs}$,

$i_{\mathrm{g}} = i_{\mathrm{gs}} + i_{\mathrm{gd}}$ and $i_{\mathrm{s}} = i_{\mathrm{gs}} - i_{\mathrm{ds}}$, we find by straightforward substitution and some basic arithmetic

$$\begin{aligned}
\langle i_{\mathrm{d}} \cdot i_{\mathrm{d}}^* \rangle &= S_{\mathrm{id}} + S_{\mathrm{ig}}/4 - \mathrm{Re}(S_{\mathrm{igid}}) \\
\langle i_{\mathrm{g}} \cdot i_{\mathrm{d}}^* \rangle &= S_{\mathrm{igid}} - S_{\mathrm{ig}}/2 \\
\langle i_{\mathrm{s}} \cdot i_{\mathrm{d}}^* \rangle &= -S_{\mathrm{id}} + S_{\mathrm{ig}}/4 - \mathrm{Im}(S_{\mathrm{igid}}) \\
\langle i_{\mathrm{g}} \cdot i_{\mathrm{g}}^* \rangle &= S_{\mathrm{ig}} \\
\langle i_{\mathrm{s}} \cdot i_{\mathrm{g}}^* \rangle &= -S_{\mathrm{igid}}^* - S_{\mathrm{ig}}/2 \\
\langle i_{\mathrm{s}} \cdot i_{\mathrm{s}}^* \rangle &= S_{\mathrm{id}} + S_{\mathrm{ig}}/4 + \mathrm{Re}(S_{\mathrm{igid}})
\end{aligned} \tag{6.5}$$

Verilog-A

In Verilog-A it is not possible to define noise sources that are frequency dependent (except for $1/f$-noise), nor is it possible to directly define correlations between noise sources. Instead, the desired model must be created by using controlled sources and the frequency transfer of passive elements.[1]

The goal is to create the three noise sources shown in Fig. 6.3 with the noise powers (including frequency dependence and correlation) as described by Eq. (6.4).

To simplify notation, we rewrite Eqs. (4.367) and (4.368) as

$$S_{\mathrm{ig}} = \frac{\boldsymbol{N}_{\mathbf{T}}}{m_{\mathrm{ig}}} \cdot |T|^2 \tag{6.6}$$

and

$$S_{\mathrm{igid}} = \frac{\boldsymbol{N}_{\mathbf{T}}}{m_{\mathrm{ig}}} \cdot m_{\mathrm{igid}} \cdot T, \tag{6.7}$$

where

$$T = \frac{j \cdot \omega \cdot \tau}{1 + j \cdot \omega \cdot \tau}, \tag{6.8}$$

$\tau = m_{\mathrm{ig}} \cdot C_{\mathrm{Geff}}$ and ω is the operating frequency.

Correlation between noise sources in verilog-A can be created by making linear combinations of independent sources. Therefore, we start with two *independent* white noise sources with current noise spectral densities S_1 and S_2 and noise currents i_1 and i_2. If we set

$$\begin{aligned}
i_{\mathrm{gs}} = i_{\mathrm{gd}} &= \frac{1}{2} \cdot \alpha_1 \cdot i_1 & (6.9)\\
i_{\mathrm{ds}} &= \beta_1 \cdot i_1 + \beta_2 \cdot i_2, & (6.10)
\end{aligned}$$

where α_1, β_1, and β_2 are certain (complex) coefficients, we get

$$\begin{aligned}
S_{\mathrm{ig}} &= 4 \cdot \langle i_{\mathrm{gd}} \cdot i_{\mathrm{gd}}^* \rangle = |\alpha_1|^2 \cdot \langle i_1 \cdot i_1^* \rangle \\
&= |\alpha_1|^2 \cdot S_1 & (6.11)\\
S_{\mathrm{id}} &= \langle i_{\mathrm{ds}} \cdot i_{\mathrm{ds}}^* \rangle = |\beta_1|^2 \cdot \langle i_1 \cdot i_1^* \rangle + \beta_1 \cdot \beta_2^* \cdot \langle i_1 \cdot i_2^* \rangle + |\beta_2|^2 \cdot \langle i_2 \cdot i_2^* \rangle \\
&= |\beta_1|^2 \cdot S_1 + |\beta_2|^2 \cdot S_2 & (6.12)\\
S_{\mathrm{igid}} &= 2 \cdot \langle i_{\mathrm{gd}} \cdot i_{\mathrm{ds}}^* \rangle = \alpha_1 \cdot \beta_1^* \cdot \langle i_1 \cdot i_1^* \rangle + \alpha_1 \cdot \beta_2^* \cdot \langle i_1 \cdot i_2^* \rangle \\
&= \alpha_1 \cdot \beta_1^* \cdot S_1. & (6.13)
\end{aligned}$$

Here we used that the noise currents i_1 and i_2 are independent, such that $\langle i_1 \cdot i_2^* \rangle = 0$. We need to choose proper values for the coefficients α_1, β_1 and β_2, as well as S_1 and S_2, such that S_{ig}, S_{id}, and S_{igid} get the correct value.

---

[1] Although this appears to be a limitation, it is in fact very helpful to ensure that the resulting noise model is consistent with time-domain simulations.

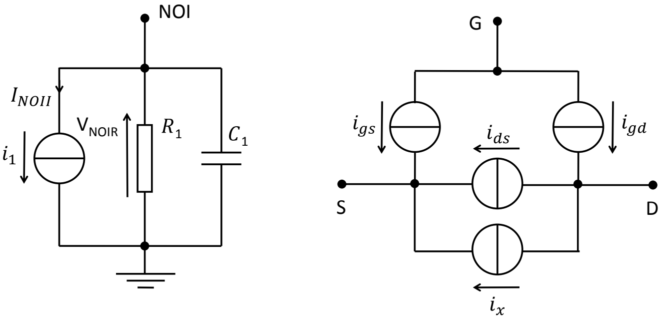

Figure 6.4: The subcircuit used in PSP's Verilog-A implementation to model the correct frequency dependence of induced gate noise and its correlation with the channel thermal noise.

There is some freedom in choosing the numbers; the values that are used in the verilog-A implementation of PSP are:

$$\alpha_1 = T \tag{6.14}$$

$$\beta_1 = m_{\text{igid}} \tag{6.15}$$

$$\beta_2 = 1 \tag{6.16}$$

$$S_1 = \boldsymbol{N}_{\mathbf{T}}/m_{\text{ig}} \tag{6.17}$$

$$S_2 = \boldsymbol{N}_{\mathbf{T}} \cdot (1 - C_{\text{igid}}^2) \cdot m_{\text{id}}, \tag{6.18}$$

where

$$C_{\text{igid}} = \frac{m_{\text{igid}}}{\sqrt{m_{\text{ig}} \cdot m_{\text{id}}}}, \tag{6.19}$$

and m_{id}, m_{ig}, and m_{igid} are given by Eqs. (4.363), (4.364), and (4.365), respectively.

Compared with previous version of PSP, the verilog-A code of PSP103.4 and later, a single equivalent circuit is used to implement frequency dependence. This subcircuit, shown in Fig. 6.4, contains a parallel connection of a white noise source with a resistor R_1 and a capacitance C_1. The parameters of these components are given by:

$$S_1 = \langle i_1 \cdot i_1^* \rangle = \boldsymbol{N}_{\mathbf{T}} \tag{6.20}$$

$$R_1 = 1\,\Omega \tag{6.21}$$

$$C_1 = m_{\text{ig}} \cdot C_{\text{Geff}} \tag{6.22}$$

where the values of C_{Geff} is given by Eqs. (4.353).

The two noise sources connected to the gate in Fig. 6.4 are as two voltage-controlled current sources with:

$$i_{\text{gd}} = i_{\text{gs}} = \frac{1}{2} \cdot T \cdot V_{\text{NOI}} \tag{6.23}$$

The third source in Fig. 6.3 (between source and drain) is realized by putting two elements in parallel, as illustrated in Fig. 6.4:

- A current-controlled current source i_{x} controlled by I_{NOII};
- A white noise source with current power spectral density $S_2 = \boldsymbol{N}_{\mathbf{T}} \cdot (1 - C_{\text{igid}}^2) \cdot m_{\text{id}}$.

Where the current i_{x} is given by:

$$i_{\mathrm{x}} = C_{\mathrm{igid}} \cdot \sqrt{m_{\mathrm{id}}} \cdot I_{\mathrm{NOII}} \tag{6.24}$$

To complete the model, we remark that from Fig. 6.3 it is clear that source-drain interchange only affects the sign of i_{ds}.

In summary, the relevant portion of the verilog-A implementation is given by (mult-scaling and labels are not included for clarity):

```
electrical NOI;

branch (NOI) NOII;
branch (NOI) NOIR;
branch (NOI) NOIC;

// subcircuit
I(NOII)      <+  white_noise((nt / mig));
I(NOIR)      <+  V(NOIR) / mig;
I(NOIC)      <+  ddt(CGeff * V(NOIC));

// noise sources ids, igs, and igd
I(GP,SI)     <+ -ddt(sqrt(MULT_i) * 0.5 * CGeff * V(NOIC));
I(GP,DI)     <+ -ddt(sqrt(MULT_i) * 0.5 * CGeff * V(NOIC));
I(DI,SI)     <+  sigVds * sqrt(MULT_i) * migid * I(NOII);
I(DI,SI)     <+  white_noise(MULT_i * sqid * sqid * (1.0 - c_igid * c_igid));
```

It is straightforward to verify that this implementation of PSP's noise model in Verilog-A naturally yields the desired correlations and frequency dependence. However, it requires two additional internal nodes.

SiMKit C-code

Contrary to the limitation of Verilog-A language, most circuit simulators are able to directly deal with correlated and frequency dependent noise—without the use of additional internal nodes. In order to minimize the simulation time of the model, C-implementations should therefore avoid the use of such internal nodes whenever possible.

In SiMKit, the frequency dependence and correlation of the noise sources indicated in Fig. 6.3 are implemented directly according to Eq. (6.4). The result is therefore equivalent to the verilog-A implementation.

In summary, even though the SiMKit-implementation of the noise model in PSP is different from that in verilog-A (as it does not make use of additional internal nodes) the result of noise noise simulations will be identical.

6.5.4 Clip warnings

From SiMKit 3.7 onwards, it is possible to set the level of clip-warning information through the value of the parameter **PARAMCHK**. This functionality is available for most SiMKit models. It is *not* available in the verilog-A version of PSP.

If the value of **PARAMCHK** is

< 0 All clip warnings are suppressed.

≥ 0 (default) Clip warnings for instance parameters.

≥ 1 Clip warnings for model parameters.

≥ 2 Clip warnings for internally computed local parameters during model initialization.

≥ 3 Clip warnings for internally computed local parameters during model evaluation.

This works in an accumulative manner: if a higher value of **PARAMCHK** is used, the warnings associated with lower levels are still included. Note that the highest level is of interest only for self heating models, where electrical parameters may change dependent on temperature. Also note that the default value (0) results in less clip warnings than in earlier versions of the model.

Section 7

Parameter extraction

The parameter extraction strategy for PSP consists of four main steps:

1. Measurements
2. Extraction of local parameters at room temperature
3. Extraction of temperature scaling parameters
4. Extraction of geometry scaling (global) parameters

The above steps will be briefly described in the following sections. Note that the description of the extraction procedure is not 'complete' in the sense that only the most important parameters are discussed and in cases at hand it may be advantageous (or even necessary) to use an adapted procedure.

Throughout this section, bias and current conditions are given for an n-channel transistor only; for a p-channel transistor, all voltages and currents should be multiplied by -1.

As explained in the introduction, the hierarchical setup of PSP (local and global level) allows for the two-step parameter extraction procedure described in this section; this is the recommended method of operation. Nevertheless, it is possible to skip the first steps and start extracting global parameters directly. This procedure is not described here, but the directions below may still be useful.

7.1 Measurements

The parameter extraction routine consists of six different DC-measurements (two of which are optional) and four capacitance measurements.[1] Measurement V and VI are only used for extraction of gate-current, avalanche, and GIDL/GISL parameters. Measurement IX and X are only used for extraction of inner fringe and overlap capacitances in channel accumulation regime.

- **Measurement I** ("idvg"): $I_{\rm D}$ vs. $V_{\rm GS}$
  $V_{\rm GS} = 0 \ldots V_{\rm sup}$ (with steps of maximum 50 mV).
  $V_{\rm DS} = 25$ or 50 mV
  $V_{\rm BS} = 0 \ldots - V_{\rm sup}$ (3 or more values)

- **Measurement II** ("idvgh"): $I_{\rm D}$ vs. $V_{\rm GS}$
  $V_{\rm GS} = 0 \ldots V_{\rm sup}$ (with steps of maximum 50 mV).
  $V_{\rm DS} = V_{\rm sup}$

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[1] The bias conditions to be used for the measurements are dependent on the supply voltage of the process. Of course it is advisable to restrict the range of voltages to this supply voltage $V_{\rm sup}$. Otherwise physical effects atypical for normal transistor operation—and therefore less well described by PSP—may dominate the characteristics.

$V_{\mathrm{BS}} = 0 \ldots -V_{\mathrm{sup}}$ (3 or more values)

- **Measurement III** ("idvd"): I_{D} vs. V_{DS}
  $V_{\mathrm{GS}} = 0 \ldots V_{\mathrm{sup}}$ (3 or more values)
  $V_{\mathrm{DS}} = 0 \ldots V_{\mathrm{sup}}$ (with steps of maximum 50 mV).
  $V_{\mathrm{BS}} = 0$ V

- **Measurement IV** ("idvdh", optional):I_{D} vs. V_{DS}
  $V_{\mathrm{GS}} = 0 \ldots V_{\mathrm{sup}}$ (3 or more values)
  $V_{\mathrm{DS}} = 0 \ldots V_{\mathrm{sup}}$ (with steps of maximum 50 mV).
  $V_{\mathrm{BS}} = -V_{\mathrm{sup}}$

- **Measurement V** ("igvg"): I_{G} and I_{B} vs. V_{GS}
  $V_{\mathrm{GS}} = -V_{\mathrm{sup}} \ldots V_{\mathrm{sup}}$ (with steps of maximum 50 mV).
  $V_{\mathrm{DS}} = 0 \ldots V_{\mathrm{sup}}$ (3 or more values)
  $V_{\mathrm{BS}} = 0$ V

- **Measurement VI** ("igvgh", optional): I_{G} and I_{B} vs. V_{GS}
  $V_{\mathrm{GS}} = -V_{\mathrm{sup}} \ldots V_{\mathrm{sup}}$ (with steps of maximum 50 mV).
  $V_{\mathrm{DS}} = 0 \ldots V_{\mathrm{sup}}$ (3 or more values)
  $V_{\mathrm{BS}} = -V_{\mathrm{sup}}$

- **Measurement VII** ("cggvg"): C_{GG} vs. V_{GS}
  $V_{\mathrm{GS}} = -V_{\mathrm{sup}} \ldots V_{\mathrm{sup}}$ (with steps of maximum 50 mV).
  $V_{\mathrm{DS}} = 0$ V
  $V_{\mathrm{BS}} = 0$ V

- **Measurement VIII** ("ccgvg"): C_{CG} vs. V_{GS}
  $V_{\mathrm{GS}} = -V_{\mathrm{sup}} \ldots V_{\mathrm{sup}}$ (with steps of maximum 50 mV).
  $V_{\mathrm{DS}} = 0$ V
  $V_{\mathrm{BS}} = 0$ V

- **Measurement IX** ("cgcvg", optional): C_{GC} vs. V_{GS}
  $V_{\mathrm{GS}} = -V_{\mathrm{sup}} \ldots 0$ (with steps of maximum 50 mV).
  $V_{\mathrm{DS}} = 0$ V
  $V_{\mathrm{BS}} = 0$ V

- **Measurement X** ("cgbvg", optional): C_{GB} vs. V_{GB}
  $V_{\mathrm{GB}} = -V_{\mathrm{sup}} \ldots V_{\mathrm{sup}}$ (with steps of maximum 50 mV).
  $V_{\mathrm{DS}} = 0$ V
  $V_{\mathrm{BS}} = 0$ V

For the extraction procedure, the transconductance g_{m} (for Measurement I and II) and the output conductance g_{DS} (for Measurement III and IV) are obtained by numerical differentiation of the measured I-V-curves. Furthermore, I_{min} is the smallest current which can reliably measured by the system (noise limit) and I_{T} is defined as 10% of the largest measured value of $|I_{\mathrm{D}}|$ in Measurement I. The latter will be used to make a rough distinction between the subthreshold and superthreshold region.

The channel-to-gate capacitance C_{CG} in Measurement VIII is the summation of the drain-to-gate capacitance C_{DG} and the source-to-gate capacitance C_{SG} (i.e., source and drain are short-circuited); it is needed to extract the overlap capacitance parameters in channel-depletion regime. However, using optional measurement IX, it is preferable to use this measurement to extract the inner fringe capacitance parameters.

The optional AC measurements (IX and X) are used to improve modeling in accumulation regime for short channel transistors.

The gate-to-channel capacitance $C_{\rm GC}$ in Measurement IX is the summation of the gate-to-drain capacitance $C_{\rm GD}$ and the gate-to-source capacitance $C_{\rm GS}$ (i.e., source and drain are short-circuited); it is optional and is needed to extract the overlap capacitance parameters in channel-depletion regime when the measurement VIII is used to extract the inner fringe capacitance parameters.

The gate-to-body capacitance $C_{\rm GB}$ in Measurement X is obtained with source and drain connected to the ground; it is optional and is needed to extract the overlap capacitance parameters in channel-accumulation regime.

The local parameter extraction measurements I through VI have to be performed at room temperature for every device. In addition, capacitance measurements VII and VIII need to be performed for at least a long/wide and a short/wide (i.e., $L = L_{\rm min}$) transistor (at room temperature). Capacitance measurements IX and X are performed for short/wide geometry only. Furthermore, for the extraction of temperature scaling parameters measurements I, III, and V have to be performed at different temperatures (at least two extra, typically $-40\,^{\circ}$C and $125\,^{\circ}$C) for at least a long wide and a short wide transistor.

7.2 Extraction of local parameters at room temperature

General remarks

The simultaneous determination of *all* local parameters for a specific device is not advisable, because the value of some parameters can be wrong due to correlation and suboptimization. Therefore it is more practical to split the parameters into several small groups, where each parameter group can be determined using specific measurements. In this section, such a procedure will be outlined.

The extraction of local parameters is performed for every device. In order to ensure that the temperature scaling relations do not affect the behavior at room temperature, the reference temperature **TR** should be set equal to room temperature.

Before starting the parameter extraction procedure, one should make sure that **SWIGATE**, **SWIMPACT**, **SWGIDL**, **SWJUNCAP**, and **TYPE** are set to the desired value. Moreover, **QMC** should be set to 1, in order to include quantum mechanical corrections in the simulations.

It is not the case that all local parameters are extracted for every device. Several parameters are only extracted for one or a few devices, while they are kept fixed for all other devices. Moreover, a number of parameters can generally be kept fixed at their default values and need only occasionally be used for fine-tuning in the optimization procedure. Details are given later in this section.

As a special case, it is generally not necessary to extract values for **AX**. In stead, they can be calculated from Eq. (3.72), using **AXO** ~ 18 and **AXL** ~ 0.25. It may be necessary to tune the latter value such that the value of **AX** is between 2 and 3 for the shortest channel in the technology under study.

It is recommended to start the extraction procedure with the long(est) wide(st) device, then the shortest device with the same width, followed by all remaining devices of the same width in order of decreasing length. Then the next widest-channel devices are extracted, where the various lengths are handled in the same order. In this way, one works ones way down to the narrowest channel devices.

AC-parameters

Some parameters (such as **TOX** and **NP**) that do affect the DC-behavior of a MOSFET can only be extracted accurately from C-V-measurements.[2] This should be done before the actual parameter extraction from DC-

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[2] Although parameter **NOV** *can* be determined from overlap gate current, it is nonetheless more accurately determined from Measurement VIII.

measurements is started. In Tables 7.1 and 7.2 the extraction procedure for the AC-parameters is given.

Starting from the default parameter set and setting **TOX** to a reasonable value (as known from technology), **VFB**, **NEFF**, **DPHIB**, **COX**, and **NP** can be extracted from C_{GG} in Measurement VII for a long, wide device. The value of **TOX** can be determined from **COX** $= \epsilon_{\mathrm{ox}} \cdot L \cdot W/$**TOX**. If the device is sufficiently long and wide, drawn length and width can be used in this formula.

Table 7.1: AC-parameter extraction procedure for a long channel MOSFET.

Step	Optimized parameters	Fitted on	Abs./Rel.	Conditions
1	**VFB**,**COX**	VII: C_{GG}	Absolute	$V_{\mathrm{GS}} < 0$
2	**NEFF**, **VFB**	VII: C_{GG}	Absolute	$V_{\mathrm{GS}} > V_{\mathrm{FB}}$ and $V_{\mathrm{GS}} < V_{\mathrm{T}}$
3	**DPHIB**, **NP**	VII: C_{GG}	Absolute	$V_{\mathrm{GS}} > V_{\mathrm{T}}$
2	Repeat Step 1			

Next, **NOV** and **CGOV** can be extracted from C_{CG} in Measurement VIII for a short, wide device (see also Table 7.1), where **VFB** and **NP** are taken from the long channel case. In general, one can assume **TOXOV** $=$ **TOX**. If Measurement VII is available for a few short/wide devices of different lengths, one can extract **TOX** and ΔL from a series of extracted values of **COX** vs. L_{draw}.

Table 7.2: AC-parameter extraction procedure for a short channel MOSFET without optional measurements IX and X. The value of **NP** are taken from the long-channel case.

Step	Optimized parameters	Fitted on	Abs./Rel.	Conditions
1	**NEFF**	VII: C_{GG}	Absolute	$V_{\mathrm{GS}} > V_{\mathrm{FB}}$ and $V_{\mathrm{GS}} < V_{\mathrm{T}}$
2	**DPHIB**, **COX**	VII: C_{GG}	Absolute	$V_{\mathrm{GS}} > V_{\mathrm{T}}$
3	**CGOV**, **NOV**, **CFR**	VIII: C_{CG}	Absolute	$V_{\mathrm{GS}} < 0$
4	Repeat Steps 1 and 2			

For accurate modeling in accumulation regime, the measurement set-up IX and X can be used. In this case, the extraction flow, described in Table 7.3, is more complex. Indeed, for each extraction of overlap capacitance and inner fringe capacitance parameters, the channel contribution must be evaluated due to the modification of the partitioning between parasitic charges and the channel charge.

Some remarks:

- If C-V-measurements are not available, one could revert to values known from the fabrication process. Note that **TOX** and **TOXOV** are *physical* oxide thicknesses; poly-depletion and quantum-mechanical effects are taken care of by the model. If the gate dielectric is not pure SiO$_2$, one should manually compensate for the deviating dielectric constant.
- In general, **VFB** and **NP** can be assumed independent of channel length and width (so, the long/wide-channel values can be used for all other devices as well). Only if no satisfactory fits are obtained, one could allow for a length dependence (for **NP**) or length *and* width dependence (for **VFB**). Then, one should proceed by extracting **VFB** and/or **NP** from capacitance measurements for various channel geometries, fit Eq. (3.15) / Eq. (3.31) to the result and use interpolated values in the DC parameter extraction procedure.
- The value of parameter **TOX** profoundly influences both the DC- and AC-behavior of the PSP-model and thus the values of many other parameters. It is therefore very important that this parameter is determined (as described above) and *fixed* before the rest of the extraction procedure is started.
- The gate-to-bulk parasitic capacitance, modeled by the parameter **CGBOV**, can be extracted by using geometry dependence of C_{GB}

Table 7.3: AC-parameter extraction procedure for a short channel MOSFET with optional measurements IX and X. The value of **NP** is taken from the long-channel case.

Step	Optimized parameters	Fitted on	Abs./Rel.	Conditions
1	**NEFF**	X: C_{GB}	Absolute	$V_{\mathrm{GS}} > V_{\mathrm{FB}}$ and $V_{\mathrm{GS}} < V_{\mathrm{T}}$
2	**DPHIB**, **COX**	IX: C_{GC}	Absolute	$V_{\mathrm{GS}} > 0$
3	**CGOV**, **NOV**, **CFR**	VIII: C_{CG}	Absolute	$V_{\mathrm{GS}} < 0$
4	**DPHIB**, **COX**	IX: C_{GC}	Absolute	$V_{\mathrm{GS}} > 0$
5	**VFB**, **DPHIB**	X: C_{GB}	Absolute	—
6	**CINR**, **CFR**	IX: C_{GC}	Absolute	$V_{\mathrm{GS}} < 0$
7	**DPHIB**, **COX**	IX: C_{GC}	Absolute	$V_{\mathrm{GS}} > 0$
8	**FCGOVACC**, **CGOVACCG**, **VFB**	X: C_{GB}	Absolute	$V_{\mathrm{GS}} < 0$
9	**FCINRDEP**	VII: C_{GG}	Absolute	$V_{\mathrm{GS}} > V_{\mathrm{FB}}$ and $V_{\mathrm{GS}} < V_{\mathrm{T}}$
10	**AXINR**, **DVFBINR**	VII: C_{GG}	Absolute	Around to $V_{\mathrm{GS}} = V_{\mathrm{FB}}$
11	**DPHIB**	VII: C_{GG}	Absolute	$V_{\mathrm{GS}} > 0$

The obtained values of **VFB**, **TOX**, **TOXOV**, **NP**, and **NOV** can now be used in the DC-parameter extraction procedure. The above values of **NEFF** and **DPHIB** can be disregarded; they will be determined more accurately from the DC-measurements.

In devices with strong lateral non-uniform doping, the threshold voltage in AC-measurements may deviate significantly from that in DC-measurements. If that is the case, values for **NEFF** and **DPHIB** obtained from DC-measurements may not be satisfactory to describe AC-measurements. Then, one has the option to set **SWDELVTAC** $= 1$, **DELVTAC** = **DPHIB**$_{\mathrm{ac}}$ − **DPHIB**$_{\mathrm{dc}}$, and **FACNEFFAC** = **NEFF**$_{\mathrm{ac}}$/**NEFF**$_{\mathrm{dc}}$ to get a good description of both the DC and the AC measurements.

An accurate model in saturation regime requires 2-ports RF-measurements. The accuracy can be obtained by using **SWQSAT** $= 1$. In this case, the model parameters **THESATAC**, **AXAC**, **ALPAC**, **ALP1AC** can be extracted from S-parameters for several drain voltages.

DC-parameters

Before the optimization is started a reasonably good starting value has to be determined, both for the parameters to be extracted and for the parameters which remain constant. For most parameters to be extracted for a *long* channel device, the default values from local parameters in Section 2.5.2 can be taken as initial values. Exceptions are given in Table 7.4. Starting from these values, the optimization procedure following the scheme below is performed. This method yields a proper set of parameters after the repetition indicated as the final step in the scheme. Experiments with transistors of several processes show that repeating those steps more than once is generally not necessary.

For an accurate extraction of parameter values, the parameter set for a long-channel transistor has to be determined first. In the long-channel case most of the mobility related parameters (i.e. **MUE** and **THEMU**) and the gate tunneling parameters (**GCO**, **GC2**, and **GC3**) are determined and subsequently fixed for the shorter-channel devices.

In Table 7.5 the complete DC extraction procedure for long-channel transistors is given. The magnitude of the simulated I_{D} and the overall shape of the simulated I_{D}-V_{GS}-curve is roughly set in Step 1. Next the parameters **NEFF**, **DPHIB**, and **CT**—which are important for the subthreshold behavior—are optimized in Step 2, neglecting short-channel effects such as drain-induced barrier-lowering (DIBL). After that, the mobility parameters are optimized in Step 3, neglecting the influence of series-resistance. In Step 4 a preliminary value of the velocity saturation parameter is obtained, and subsequently the conductance parameters **ALP**, **ALP1**, and **VP** are determined in Step 5. A more accurate value of **THESAT** can now be obtained using Step 6. The gate current parameters are determined in Steps 7 and 8, where it should be noted that **GCO** should only be

Table 7.4: Initial values for local parameter extraction for a *long*-channel device. For parameters which are not listed in this table, the default value (as given in Section 2.5.2) can be used as initial value.

Parameter	**Initial value**
BETN	$0.03 \cdot W/L$
RS	0
THESAT	0.1
AX	12
A1	0

Table 7.5: DC-parameter extraction procedure for a long-channel MOSFET. The parameters **VFB**, **TOX**, **TOXOV**, **NP**, and **NOV** must be taken from C-V-measurements. The optimization is either performed on the absolute or relative deviation between model and measurements, as shown in the table.

Step	**Optimized parameters**	**Fitted on**	**Abs./Rel.**	**Conditions**
1	**NEFF**, **BETN**, **MUE**, **THEMU**[a]	I: I_D	Absolute	–
2	**NEFF**, **DPHIB**, **CT**, **GFACNUD**	I: I_D	Relative	$I_\mathrm{min} < I_\mathrm{D} < I_\mathrm{T}$
3	**CT**, **CTG**, **CTB**	I: $g_\mathrm{m}/I_\mathrm{D}$	Absolute	–
4	**MUE**, **THEMU**[a], **CS**, **THECS**, **XCOR**, **BETN**	I: I_D, g_m	Absolute	–
5	**THESAT**	III: I_D	Absolute	–
6	**ALP**, **ALP1**, **VP**[a], (**AX**)	III: g_DS	Relative	–
7	**THESAT**	II: I_D	Absolute	–
8	**IGINV**, **GC2**[a], **GC3**[a]	V: I_G	Relative	$I_\mathrm{G} > I_\mathrm{min}$
9	**IGOV**, (**GCO**[a])	V: I_G	Relative	$V_\mathrm{GS} < 0$ V, $I_\mathrm{G} < -I_\mathrm{min}$
10	**A1**, **A2**[a], **A3**	V: I_B	Relative	$V_\mathrm{GS} > 0$ V, $I_\mathrm{B} < -I_\mathrm{min}$
11	**A4**	VI: I_B	Relative	$V_\mathrm{GS} > 0$ V, $I_\mathrm{B} < -I_\mathrm{min}$
12	**AGIDL**, **BGIDL**[a]	V: I_B	Relative	$V_\mathrm{GS} < 0$ V, $I_\mathrm{B} < -I_\mathrm{min}$
13	**CGIDL**[a]	VI: I_B	Relative	$V_\mathrm{GS} < 0$ V, $I_\mathrm{B} < -I_\mathrm{min}$
14	Repeat Steps 2 – 12			

---

[a] Only extracted for the *widest* long channel device and fixed for all other geometries.

extracted if the influence of gate-to-bulk tunneling is visible in the measurements. This is usually the case if $V_\mathrm{sup} \gtrsim |$**VFB**$|$. This is followed by the weak-avalanche parameters in Step 9 and (optionally) 10, and finally, the gate-induced leakage current parameters are optimized in Step 11 and (optionally) 12.

After completion of the extraction for the long-channel device, it is recommended to first extract parameters for the shortest-channel device (of the same width). The mobility-reduction parameters (**MUE**, **THEMU**) and the gate tunneling probability factors (**GCO**, **GC2**, **GC3**) found from the corresponding long-channel device should be used. The extraction procedure as given in Table 7.6 should be used.

Once the value for **RS** has been found from the shortest device, it should be copied into the long-channel parameter set and steps 2–3 (Table 7.5) should be repeated, possibly leading to some readjustment of **MUE** and **THEMU**. If necessary, this procedure must be repeated. Similarly—once the value of **THESATG** and **THESATB** have been determined from the shortest widest channel device—steps 4, 5, and 6 of the long-channel extraction procedure (Table 7.5) must be repeated to obtain updated values for **THESAT**, **ALP**, **ALP1**, and **CFD**.

Table 7.6: DC-parameter extraction procedure for a short-channel MOSFET. Parameters **MUE**, **THEMU**, **VP**, **GCO**, **GC2**, **GC3**, **A2**, **A4**, **BGIDL**, and **CGIDL** are taken from the corresponding long-channel case. The optimization is either performed on the absolute or relative deviation between model and measurements, as indicated in the table.

Step	Optimized parameters	Fitted on	Abs./Rel.	Conditions
1	**DPHIB**, **BETN**, **RS**[a]	I: I_D	Absolute	–
2	**NEFF**, **DPHIB**, **PSCE**, **GFACNUD**, **VSBNUD**[b], **DVSBNUD**[b]	I: I_D	Relative	$I_\mathrm{min} < I_\mathrm{D} < I_\mathrm{T}$
3	**BETN**, **RS**[a], **RSG**[b], **XCOR**	I: I_D, g_m	Absolute	–
4	**CF**, **CFB**[b], **PSCED**[b], **PSCEB**[b]	II: I_D	Relative	–
4	**THESAT**, **THESATG**[b]	II: I_D	Absolute	–
5	**ALP**, **ALP1**, **CFD**, (**AX**)	III: g_DS	Relative	–
7	**THESAT**	II: I_D, g_m	Absolute	–
8	**IGINV**, **IGOV**	V: I_G	Relative	$\lvert I_\mathrm{G}\rvert > I_\mathrm{min}$
9	**A1**, **A3**	V: I_B	Relative	$V_\mathrm{GS} > 0$ V, $I_\mathrm{B} < -I_\mathrm{min}$
10	**AGIDL**	V: I_B	Relative	$V_\mathrm{GS} < 0$ V, $I_\mathrm{B} < -I_\mathrm{min}$
11	Repeat Steps 2 – 10			

---

[a] Only extracted for the *shortest* channel of each width and fixed for all other geometries.

[b] Only extracted for the *shortest widest* device and fixed for all other geometries.

If consistent parametersets have been found for the longest and shortest channel device, the extraction procedure as given in Table 7.6 can be executed for all intermediate channel lengths. The extracted parameter values of the next-longer device can be used as initial values.

Finally, the parameters **GFACNUD**, **VSBNUD**, and **DVSBNUD** should only be used if the description of the body effect is not satisfactory otherwise. For this, the NUD-model must be invoked by setting **SWNUD** $= 1$.

7.3 Extraction of Temperature Scaling Parameters

For a specific device, the temperature scaling parameters can be extracted after determination of the local parameters at room temperature. In order to do so, measurements I, II and IV need to be performed at various temperature values (at least two values different from room temperature, typically $-40\,°\mathrm{C}$ and $125\,°\mathrm{C}$), at least for a long wide device and a short wide device. If the reference temperature **TR** has been chosen equal to room temperature (as recommended in Section 7.2), the modeled behavior at room temperature is insensitive to the value of the temperature scaling parameters. As a first-order estimate of the temperature scaling parameter values, the default values as given by local parameters in Section 2.5.2 can be used. Again the parameter extraction scheme is slightly different for the long-channel and for the short-channel case.

For an accurate extraction, the temperature scaling parameters for a long-wide-channel device have to be determined first. In the long-wide-channel case the carrier mobility parameters can be determined, and they are subsequently fixed for all other devices. In Table 7.7 the appropriate extraction procedure is given. In Step 1 the subthreshold temperature dependence is optimized, followed by the optimization of mobility reduction parameters in Step 2. Next the temperature dependence of velocity saturation is optimized in Step 3. In the subsequent steps, parameters for the temperature dependence of the gate current, the impact ionization current and gate-induced drain leakage are determined. The determined values of the mobility reduction temperature scaling parameters (i.e., **STMUE**, **STTHEMU**, **STCS**, **STTHECS** and **STXCOR**) are copied to all other devices and kept fixed during the remainder of the temperature-scaling parameter extraction procedure. Step 1 and 2 could then be performed on one or more long narrow devices as well (for **STVFB**, **STBETN**, and **STTHESAT** only).

Table 7.7: Temperature scaling parameter extraction procedure for a long wide channel MOSFET. This scheme only makes sense if measurements have been performed at one or (preferably) more temperatures which differ from room temperature.

Step	Optimized parameters	Fitted on	Abs./Rel.	Conditions
1	**STVFB**[a]	I: I_D	Relative	$I_\mathrm{D} < I_\mathrm{T}$
2	**STBETN**[a], **STMUE**, **STTHEMU**, **STCS**, **STTHECS**, **STXCOR**	I: I_D	Absolute	–
3	**STTHESAT**[a]	II: I_D	Absolute	–
4	**STIG**	V: I_G	Relative	$\lvert I_\mathrm{G}\rvert > I_\mathrm{min}$
5	**STA2**	V: I_B	Relative	$V_\mathrm{GS} > 0$ V, $I_\mathrm{B} < -I_\mathrm{min}$
6	**STBGIDL**	V: I_B	Relative	$V_\mathrm{GS} < 0$ V, $I_\mathrm{B} < -I_\mathrm{min}$

---

[a] Also extracted for one or more long *narrow* devices.

Table 7.8: Temperature scaling parameter extraction procedure for short-channel MOSFETs (both wide and narrow). This scheme only makes sense if measurements have been performed at one or (preferably) more temperatures which differ from room temperature.

Step	Optimized parameters	Fitted on	Abs./Rel.	Conditions
1	**STVFB**	I: I_D	Relative	$V_\mathrm{GS} < V_\mathrm{T}$
2	**STBETN**, **STRS**[a]	I: I_D	Absolute	$V_\mathrm{GS} > V_\mathrm{T}$
3	**STTHESAT**	II: I_D	Absolute	–

---

[a] Only extracted for a short *narrow* device and fixed for all other geometries.

Next the extraction procedure as given in Table 7.8 is carried out for several short devices of different widths. Preferably, the extraction is done first for a short narrow device, such that the determined value of **STRS** can be used during the extraction of the wider devices.

7.4 Extraction of Geometry Scaling Parameters

The aim of the complete extraction procedure is the determination of the geometry scaling parameters (global parameters), i.e., a single set of parameters (see Section 2.5.2) which gives a good description of the MOSFET-behavior over the full geometry range of a CMOS technology.

Determination of ΔL and ΔW

An extremely important part of the geometry scaling extraction scheme is an accurate determination of ΔL and ΔW, see Eqs. (3.7) and (3.8).[3] Since it affects the DC-, the AC- as well as the noise model and, moreover, it can heavily influence the quality of the resulting global parameter set, it is very important that this step is carried out with care.

Traditionally, ΔW can be determined from the extrapolated zero-crossing in **BETN** versus mask width W. In a similar way ΔL can be determined from $1/$**BETN** versus mask length L. For modern MOS devices with pocket implants, however, it has been found that the above ΔL extraction method is no longer valid [13, 14].

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[3] Note that ΔL_PS and ΔW_OD are expected to be known from the fabrication process. So, in fact, only **LAP** and **WOT** are extracted from the electrical measurements.

Another, more accurate method is to measure the gate-to-bulk capacitance C_{GB} in accumulation for different channel lengths [14, 15]. In this case the extrapolated zero-crossing in the C_{GB} versus mask length L curve will give ΔL. Similarly, the extracted values for **COX** (from the procedure in Table 7.1 and 7.2) vs. mask length L may be used for this purpose. Unfortunately for CMOS technologies in which gate current is non-negligible, capacitance measurements may be hampered by gate current [16]. In this case gate current parameter **IGINV** plotted as a function of channel length L may be used to extract ΔL [16]. If possible, ΔL extraction from C-V-measurements is the preferred method.

Finally, **LOV** can be obtained from (a series of) extracted values of **CGOV** from one or more short devices.

From local to global

First of all, the global parameters **TYPE**, **QMC**, and the ‘switch’-parameters should be set to the appropriate value. Next, parameters for which no geometrical scaling rules exist must be taken directly from the local set (this applies to **TR**, **TOXO**, **VNSUBO**, **DVSBNUDO**, **TOXOVO**, **NOVO**, **CTGO**, **CTBO**, **CFDO**, **CFBO**, **PSCEDO**, **PSCEBO**, **STMUEO**, **THEMUO**, **STTHEMUO**, **STCSO**, **STTHECSO**,**STXCORO**, **FETAO**, **STRSO**, **RSBO**, **RSGO**, **THESATBO**, **THESATGO**, **VPO**, **A2O**, **STA2O**, **GCOO**, **STIGO**, **GC2O**, **GC3O**, **CHIBO**, **BGIDLO**, **STBGIDLO**, **CGIDLO**, and **DTA**). Generally, these parameters have been left at their default values or they have been extracted for one device only and subsequently fixed for all other devices. The parameters **LVARO**, **LVARL**, **LVARW**, **WVARO**, **WVARL**, and **WVARW** should be known from technology.

Once the values of ΔL and ΔW are firmly established (as described above), **LAP** and **WOT** can be set and the actual extraction procedure of the geometry scaling parameters can be started. It consists of several *independent* sub-steps (which can be carried out in random order), one for each geometry dependent local parameter.

To illustrate such a sub-step, the local parameter **PSCE** is taken as an example. The relevant geometry scaling equation from Section 3.3 is Eq. (3.43), from which it can be seen that **PSCEL**, **PSCELEXP**, and **PSCEW** are the global parameters which determine the value of **PSCE** as a function of L and W. First, the extracted **PSCE** of each device in a length-series of measured (preferably wide) devices are considered as a function of L. In this context **PSCEL** and **PSCELEXP** are optimized such that the fit of Eq. (3.43) to the extracted **PSCE**-values is as good as possible, while keeping **PSCEW** fixed at 0. Then **PSCEW** is determined by considering the extracted **PSCE**-values from a length-series of measured narrow devices. Finally, the four global parameters may be fine-tuned by optimizing all four parameters to all extracted **PSCE**-values simultaneously. The default values given in Section 2.5.2 are good initial values for the optimization procedure.

All other parameters can be extracted in a similar manner. The local parameters **BETN** and **NEFF** have quite complicated scaling rules, particularly due to the non-uniform doping profiles employed in modern CMOS technologies. Therefore, a few additional guidelines are in place.

- The optimization procedure for **BETN** is facilitated if not **BETN**, but $\mathbf{BETN}_{\mathrm{sq}} \overset{\mathrm{def}}{=} \mathbf{BETN} \cdot L_{\mathrm{E}}/W_{\mathrm{E}}$ is considered.
- Starting from the default values, first **UO**, **FBET1**, **LP1**, **FBET2**, and **LP2** should be determined from a length-series of wide devices. Then **BETW1**, **BETW2**, and **WBET** should be determined from a width-series of long devices. Finally, **FBET1W** and **LP1W** can be found by considering some short narrow devices.
- Starting from the default values, first extract **FOL1**, **FOL2**, **NSUBO**, **NPCK**, and **LPCK** from a length-series of wide devices. Here, **NSUBO** determines the long-channel value of **NEFF**. Moreover, **NPCK** and **LPCK** determine the increase of **NEFF** for shorter channels (reverse short channel effect), while **FOL1** and **FOL2** are used to describe the decrease of **NEFF** for very short channels (short channel effect).
- Then **NSUBW** and **WSEG** can be determined form a width-series of long devices. Finally, **NPCKW**, **LPCKW** and **WEGP** are determined from a width-series of short devices.
- Especially for **BETN** and **NEFF** it is advisable—after completing the procedure described above—to fine tune the global parameters found by considering all extracted values of **BETN** (or **NEFF**) simultaneously.

Note that in many cases it may not be necessary to use the full flexibility of PSP's parameter scaling, e.g., for many technologies **NP** and **VFB** may be considered as independent of geometry. If such a geometry-independence is anticipated, the corresponding local parameter should be fixed during local parameter extraction. Only if the resulting global parameter set is not satisfactory, the parameter should be allowed to vary during a subsequent optimization round.

Fine tuning

Once the complete set of global parameters is found, the global model should give an accurate description of the measured I-V-curves and capacitance measurements. Either for fine tuning or to facilitate the extraction of global parameters for which the geometry scaling of the corresponding extracted local parameters is not well-behaved, there are two more things that can be done.

- Local parameters for which the fitting of global parameters was completed satisfactorily could be replaced by the values calculated from the geometrical scaling rules and fixed. Then one could redo (parts of) the local parameter extraction procedure for the remaining local parameters, making them less sensitive for cross-correlations.
- Small groups of global parameters may be fitted directly to the measurements of a well-chosen series of devices, using the global model.

7.5 Summary – Geometrical scaling

Summarizing, for the determination of a full parameter set, the following procedure is recommended.

1. Determine local parameter sets (**VFB**, **NEFF**, . . .) for all measured devices, as explained in Section 7.2 and 7.3.
2. Find ΔL and ΔW.
3. Determine the global parameters by fitting the appropriate geometry scaling rules to the extracted local parameters.
4. Finally, the resulting global can be fine-tuned, by fitting the result of the scaling rules and current equations to the measured currents of all devices simultaneously.

Section 8

DC Operating Point Output

The DC operating point output facility gives information on the state of a device at its operation point. Beside terminal currents and voltages, the magnitudes of internal elements are given. In some cases meaningful quantities can be derived which are then also given (e.g., f_{T}). The objective of the DC operating point facility is twofold:

- Calculate small-signal equivalent circuit element values
- Open a window on the internal bias conditions of the device and its basic capabilities.

All accessible quantities are described in the table below. The symbols in the 'value' column are defined in Section 4 or by complex equations in Section 8.3.

8.1 Configurable Operating Point Output

For PSP104, the convention of OP output is configurable thanks to 2 switches:

- **SWOPDRAIN**: drain definition.
- **SWOPPMOS**: PMOS convention.

To conserve the same definition as in PSP103.x, the switches must be set to **SWOPDRAIN**=0 and **SWOPPMOS**=1, corresponding to the default values. In this configuration, for *all* operating point output, the signs are configurable dependence such as if the device is an NMOS. Moreover, whenever there is a reference to the 'drain', this is always the terminal which is acting as drain for the actual bias conditions. This is even true for variables such as **vds** (which is therefore always positive) and the junction-related variables. The output variable **sdint** shows whether or not this 'drain' is the same as the terminal which was named 'drain' in the simulator.

8.1.1 Drain definition

The definition of the drain is managed by **SWOPDRAIN**. By chosing the drain as the electrical node such as the internal variable **vds** is positive, the switch should be set to 0. In this case, if $V_d - V_s$ is negative, the drain and source are interchanged as in the code (see Fig.8.1). Nevertheless, if the switch is set to 1, the drain is the first terminal in the circuit netlist whatever $V_d - V_s$ (it can be negative).

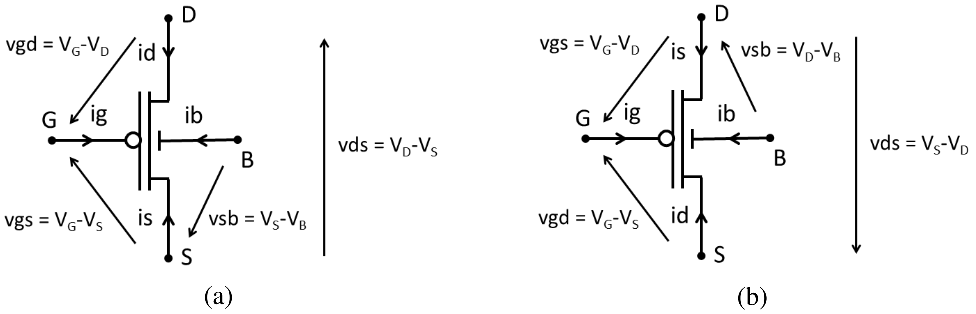

Figure 8.1: Definition of the drain when **SWOPDRAIN** = 0: (a) if $V_d - V_s \geq 0$; (b) if $V_d - V_s < 0$

8.1.2 PMOS convention

Using the switch **SWOPPMOS**, the convention for PMOS transistor can be defined. if its value is set to 0, the NMOS convention is used. In this case, the signs of all quantities are the same as for NMOS transistor similarly to PSP103.x versions (Fig.8.2.a). Otherwise, with **SWOPPMOS**=1, the type of PMOS is preserved (Fig.8.2.b). For example, the threshold voltage will be negative with this configuration.

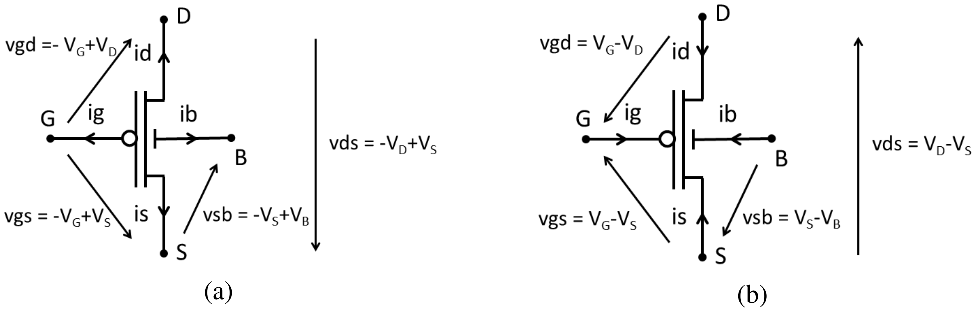

Figure 8.2: Definition of the PMOS convention: (a) with **SWOPPMOS** = 0 (similar to PSP103.x); (b) with **SWOPPMOS** = 1 (NMOS convention)

8.2 List of Operating Point Variables

No.	Name	Unit	Value	Description
			Device geometry and temperature	
0	**weff**	m	$W_{\rm E}$	Effective channel width for geometrical models
1	**leff**	m	$L_{\rm E}$	Effective channel length for geometrical models
2	**tk**	K	$T_{\rm KD}$	Device Temperature
			Bias convention	
3	**ctype**	–	1 for NMOS, -1 for PMOS	Flag for channel-type
4	**sdint**	–	1 if $V'_{\rm DS} \geq 0,\ -1$ otherwise	Flag for source-drain interchange
			Current components	

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No.	Name	Unit	Value	Description
5	**id**	A	I_D	Total drain current
6	**ig**	A	I_G	Total gate current
7	**is**	A	I_S	Total source current
8	**ib**	A	I_B	Total bulk current
9	**idsch**	A	$I_\mathrm{DS} + I_\mathrm{DSedge}$	Channel current incl. edge transistor current
10	**ids**	A	I_DS	Drain-source current, excl. edge transistor currents, avalanche, tunnel, GISL, GIDL, and junction currents
11	**igs**	A	$I_\mathrm{GCS} + I_\mathrm{GSov}$	Gate-source tunneling current
12	**igd**	A	$I_\mathrm{GCD} + I_\mathrm{GDov}$	Gate-drain tunneling current
13	**igb**	A	I_GB	Gate-bulk tunneling current
14	**idb**	A	$I_\mathrm{avl} + I_\mathrm{gidl} - I_\mathrm{j,D}$	Drain to bulk current
15	**isb**	A	$I_\mathrm{gisl} - I_\mathrm{j,S}$	Source to bulk current
16	**igcs**	A	I_GCS	Gate-channel tunneling current (source component)
17	**igcd**	A	I_GCD	Gate-channel tunneling current (drain component)
18	**iavl**	A	I_avl	Substrate current due to weak avalanche
19	**igisl**	A	I_gisl	Gate-induced source leakage current
20	**igidl**	A	I_gidl	Gate-induced drain leakage current
21	**ijs**	A	$I_\mathrm{j,S}$	Total source junction current
22	**ijd**	A	$I_\mathrm{j,D}$	Total drain junction current
23	**idsedge**	A	I_DSedge	Drain current of edge transistors
Voltages				
24	**vgs**	V	$V_\mathrm{G} - V_\mathrm{S}$	Gate-source voltage
25	**vgd**	V	$V_\mathrm{G} - V_\mathrm{D}$	Gate-drain voltage
26	**vds**	V	$V_\mathrm{D} - V_\mathrm{S}$	Drain-source voltage
27	**vsb**	V	$V_\mathrm{S} - V_\mathrm{B}$	Source-bulk voltage
28	**vdb**	V	$V_\mathrm{D} - V_\mathrm{B}$	Drain-bulk voltage
29	**vgs_i**	V	$V_\mathrm{GP} - V_\mathrm{SI}$	Internal gate-source voltage
30	**vgd_i**	V	$V_\mathrm{GP} - V_\mathrm{DI}$	Internal gate-drain voltage
31	**vds_i**	V	$V_\mathrm{DI} - V_\mathrm{SI}$	Internal drain-source voltage
32	**vsb_i**	V	$V_\mathrm{SI} - V_\mathrm{BP}$	Internal source-bulk voltage
33	**vdb_i**	V	$V_\mathrm{DI} - V_\mathrm{BP}$	Internal drain-bulk voltage
34	**vtho**	V	$Eq.\ (8.2)$	Zero-bias threshold voltage
35	**vth**	V	$Eq.\ (8.3)$	Threshold voltage including back bias and drain bias effects
36	**vthac**	V	$Eq.\ (8.5)$	Threshold voltage for charge in case of lateral non-uniform doping profile (SWDELVTAC=1)
37	**vgt**	V	**vgs_i** − **vth**	Effective gate drive voltage including back bias and drain bias effects
38	**vdsat**	V	V_dsat	Drain saturation voltage at actual bias
39	**vdsat_marg**	V	**vds** − **vdsat**	Saturation limit
Small-signal equivalent circuit				

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No.	Name	Unit	Value	Description
40	**gm_i**	S	*Eq.* (8.23)	Intrinsic transconductance
41	**gmb_i**	S	*Eq.* (8.24)	Intrinsic substrate transconductance
42	**gds_i**	S	*Eq.* (8.25)	Intrinsic output conductance
43	**gm**	S	*Eq.* (8.26)	Transconductance
44	**gmb**	S	*Eq.* (8.27)	Substrate transconductance
45	**gds**	S	*Eq.* (8.28)	Output conductance
46	**gjd**	S	*Eq.* (8.14)	Drain junction conductance
47	**gjs**	S	*Eq.* (8.15)	Source junction conductance
48	**cdd_i**	F	*Eq.* (8.69)	Intrinsic drain capacitance
49	**cdg_i**	F	*Eq.* (8.70)	Intrinsic drain-gate capacitance
50	**cdb_i**	F	*Eq.* (8.71)	Intrinsic drain-bulk capacitance
51	**cds_i**	F	**cdd_i** − **cdg_i** − **cdb_i**	Intrinsic drain-source capacitance
52	**cgd_i**	F	*Eq.* (8.72)	Intrinsic gate-drain capacitance
53	**cgg_i**	F	*Eq.* (8.73)	Intrinsic gate capacitance
54	**cgb_i**	F	*Eq.* (8.74)	Intrinsic gate-bulk capacitance
55	**cgs_i**	F	**cgg_i** − **cgd_i** − **cgb_i**	Intrinsic gate-source capacitance
56	**cbd_i**	F	*Eq.* (8.71)	Intrinsic bulk-drain capacitance
57	**cbg_i**	F	*Eq.* (8.76)	Intrinsic bulk-gate capacitance
58	**cbb_i**	F	*Eq.* (8.77)	Intrinsic bulk capacitance
59	**cbs_i**	F	**cbb_i** − **cbd_i** − **cbg_i**	Intrinsic bulk-source capacitance
60	**csd_i**	F	**cdd_i** − **cgd_i** − **cbd_i**	Intrinsic source-drain capacitance
61	**csg_i**	F	**cgg_i** − **cbg_i** − **cbg_i**	Intrinsic source-gate capacitance
62	**csb_i**	F	**css_i** − **csg_i** − **csd_i**	Intrinsic source-bulk capacitance
63	**css_i**	F	**cds_i** + **cgs_i** + **cbs_i**	Intrinsic source capacitance
64	**cgdol**	F	*Eq.* (8.33)	Total gate-drain overlap capacitance
65	**cgsol**	F	*Eq.* (8.35)	Total gate-source overlap capacitance
66	**cgbol**	F	*Eq.* (8.36)	Total gate-bulk overlap capacitance
67	**cjd**	F	*Eq.* (8.38)	Total drain junction capacitance
68	**cjs**	F	*Eq.* (8.40)	Total source junction capacitance
69	**rgate**	Ohm	**RG**	Gate resistance
70	**rdrain**	Ohm	**RDE**	External drain resistance
71	**rsource**	Ohm	**RSE**	External source resistance
72	**rbbulk**	Ohm	**RBULK**	Bulk resistance
73	**rjundrain**	Ohm	**RJUND**	Drain-side bulk resistance
74	**rjunsource**	Ohm	**RJUNS**	Source-side bulk resistance
75	**rbwell**	Ohm	**RWELL**	Well resistance
			Noise sources and associated FoM	
76	**sfl**	A^2/Hz	*Eq.* (8.78)	Flicker noise current spectral density at 1 Hz
77	**sid**	A^2/Hz	*Eq.* (8.80)	White noise current spectral density
78	**sig**	A^2/Hz	*Eq.* (8.87)	Induced gate noise current spectral density at 1 kHz
79	**cigid**	-	*Eq.* (8.88)	Imaginary part of correlation coefficient between Sig and Sid

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No.	Name	Unit	Value	Description
80	**fknee**	Hz	$S_{\rm fl}/S_{\rm id}$	Cross-over frequency above which white noise is dominant
81	**sigs**	A^2/Hz	$Eq.$ (8.89)	Gate-source current noise spectral density
82	**sigd**	A^2/Hz	$Eq.$ (8.90)	Gate-drain current noise spectral density
83	**sibs**	A^2/Hz	$Eq.$ (8.91)	Bulk-source current noise spectral density
84	**sibd**	A^2/Hz	$Eq.$ (8.92)	Impact ionization current noise spectral density
85	**sijs**	A^2/Hz	$S_{\rm I_{j,S}}$	Total source junction current noise spectral density
86	**sijd**	A^2/Hz	$S_{\rm I_{j,D}}$	Total drain junction current noise spectral density
87	**sirg**	A^2/Hz	$S_{\rm R_G}$	Noise spectral density induced by the gate resistance
88	**sird**	A^2/Hz	$S_{\rm R_D}$	Noise spectral density induced by the external drain resistance
89	**sirs**	A^2/Hz	$S_{\rm R_S}$	Noise spectral density induced by the external source resistance
90	**sirbulk**	A^2/Hz	$S_{\rm R_{BULK}}$	Noise spectral density induced by the bulk resistance
91	**sirjund**	A^2/Hz	$S_{\rm R_{JUND}}$	Noise spectral density induced by the drain-side bulk resistance
92	**sirjuns**	A^2/Hz	$S_{\rm R_{JUNS}}$	Noise spectral density induced by the source-side bulk resistance
93	**sirwell**	A^2/Hz	$S_{\rm R_{WELL}}$	Noise spectral density induced by the well resistance
Analog FoM				
94	**vgain**	-	$\textbf{gm\_i}/\textbf{gds\_i}$	Transistor gain
95	**rout**	Ohm	$1/\textbf{gds\_i}$	Small-signal output resistance
96	**vearly**	V	$\textbf{ids}/\textbf{gds\_i}$	Equivalent Early voltage
97	**beff**	A/V^2	$2 \cdot \lvert\textbf{ids}\rvert / \textbf{vgt}^2$	Gain factor
98	**gmoverid**	S	$\textbf{gm\_i}/\textbf{ids}$	Transconductor efficiency
99	**ft**	Hz	$Eq.$ (8.93)	Unity gain frequency at actual bias
Power dissipation and temperature rise induced by SHE				
100	**pdiss**	W	$P_{\rm diss}$	Power dissipation
101	**dtsh**	K	$T_{\rm KD} - T_{\rm KA}$	Temperature rise due to self heating

8.3 Equations of Operating Point Variables

Threshold Voltage Equations

$$P_{\rm D,dc,op} = 1 + \frac{G_{dc}}{4} \cdot \boldsymbol{k}_{\mathbf{P}} \tag{8.1}$$

$$\textbf{vtho} = \boldsymbol{V}_{\mathbf{FB}} + P_{\rm D,dc,op} \cdot (\boldsymbol{\phi}_{\mathbf{B,dc}} + 2 \cdot \phi_{\rm T}) + G_{\rm dc} \cdot \sqrt{\phi^*_{\rm T,dc} \cdot (\boldsymbol{\phi}_{\mathbf{B,dc}} + 2 \cdot \phi_{\rm T})} \tag{8.2}$$

$$\textbf{vth} = \boldsymbol{V_{\mathbf{FB}}} + P_{\mathrm{D,dc,op}} \cdot \left(\boldsymbol{V^{*}_{\mathbf{SB,dc}}} + \boldsymbol{\phi_{\mathbf{B,dc}}} - \Delta\phi_{\mathrm{B,dc}} + 2 \cdot \phi_{\mathrm{T}}\right) + \\ + G_{\mathrm{dc}} \cdot \sqrt{\phi^{*}_{\mathrm{T,dc}} \cdot \left(\boldsymbol{V^{*}_{\mathbf{SB,dc}}} + \boldsymbol{\phi_{\mathbf{B,dc}}} - \Delta\phi_{\mathrm{B,dc}} + 2 \cdot \phi_{\mathrm{T}}\right)} \tag{8.3}$$

$$P_{\mathrm{D,ac,op}} = 1 + \frac{G_{ac}}{4} \cdot \boldsymbol{k_{\mathbf{P}}} \tag{8.4}$$

$$\textbf{vthac} = \boldsymbol{V_{\mathbf{FB}}} + P_{\mathrm{D,ac,op}} \cdot \left(\boldsymbol{V^{*}_{\mathbf{SB,ac}}} + \boldsymbol{\phi_{\mathbf{B,ac}}} - \Delta\phi_{\mathrm{B,ac}} + 2 \cdot \phi_{\mathrm{T}}\right) + \\ + G_{\mathrm{ac}} \cdot \sqrt{\phi^{*}_{\mathrm{T,ac}} \cdot \left(\boldsymbol{V^{*}_{\mathbf{SB,ac}}} + \boldsymbol{\phi_{\mathbf{B,ac}}} - \Delta\phi_{\mathrm{B,ac}} + 2 \cdot \phi_{\mathrm{T}}\right)} \tag{8.5}$$

8.3.1 Small-Signal Equivalent Circuit

Conductances and transconductances

$$g'_{\mathrm{m,i}} = \frac{\partial(I_{\mathrm{DS}} + I_{\mathrm{DSedge}})}{\partial V_{\mathrm{GP}}} \tag{8.6}$$

$$g'_{\mathrm{mb,i}} = \frac{\partial(I_{\mathrm{DS}} + I_{\mathrm{DSedge}})}{\partial V_{\mathrm{BP}}} \tag{8.7}$$

$$g'_{\mathrm{ds,i}} = \frac{\partial(I_{\mathrm{DS}} + I_{\mathrm{DSedge}})}{\partial V_{\mathrm{DI}}} \tag{8.8}$$

$$g'_{\mathrm{m}} = \frac{\partial I_{\mathrm{D}}}{\partial V_{\mathrm{GP}}} \tag{8.9}$$

$$g'_{\mathrm{mb}} = \frac{\partial I_{\mathrm{D}}}{\partial V_{\mathrm{BP}}} \tag{8.10}$$

$$g'_{\mathrm{ds}} = \frac{\partial I_{\mathrm{D}}}{\partial V_{\mathrm{DI}}} \tag{8.11}$$

$$g'_{\mathrm{bd}} = \frac{\partial(I_{\mathrm{avl}} + I_{\mathrm{gidl}})}{\partial V_{\mathrm{DI}}} + Gmin \tag{8.12}$$

$$g'_{\mathrm{bs}} = \frac{\partial I_{\mathrm{gisl}}}{\partial V_{\mathrm{SI}}} + Gmin \tag{8.13}$$

$$g_{\mathrm{jd}} = -\partial I_{\mathrm{j,D}} / \partial V_{\mathrm{DI}} \tag{8.14}$$

$$g_{\mathrm{js}} = -\partial I_{\mathrm{j,S}} / \partial V_{\mathrm{SI}} \tag{8.15}$$

$$f_{\mathrm{j,d}} = \textbf{RDE} \cdot (g'_{\mathrm{bd}} + g_{\mathrm{jd}}) \tag{8.16}$$

$$f_{\mathrm{j,s}} = \textbf{RSE} \cdot (g'_{\mathrm{bs}} + g_{\mathrm{js}}) \tag{8.17}$$

$$h_{\mathrm{j,d}} = 1 + f_{\mathrm{j,d}} \tag{8.18}$$

$$h_{\mathrm{j,s}} = 1 + f_{\mathrm{j,s}} \tag{8.19}$$

$$f_{\mathrm{d}} = \mathbf{RDE} \cdot g'_{\mathrm{ds,i}} \tag{8.20}$$

$$f_{\mathrm{s}} = \mathbf{RSE} \cdot \left(g'_{\mathrm{m,i}} + g'_{\mathrm{mb,i}} + g'_{\mathrm{ds,i}}\right) \tag{8.21}$$

$$g_{\mathrm{fact}} = 1/\left(h_{\mathrm{j,s}} \cdot h_{\mathrm{j,d}} + f_{\mathrm{s}} \cdot h_{\mathrm{j,d}} + f_{\mathrm{d}} \cdot h_{\mathrm{j,s}}\right) \tag{8.22}$$

$$\mathbf{gm\_i} = \begin{cases} g_{\mathrm{fact}} \cdot h_{\mathrm{j,s}} \cdot g'_{\mathrm{m,i}} & \text{if } \mathbf{SWOPREXT} = 1 \\ g'_{\mathrm{m,i}} & \text{else} \end{cases} \tag{8.23}$$

$$\mathbf{gmb\_i} = \begin{cases} g_{\mathrm{fact}} \cdot \left(g'_{\mathrm{mb,i}} - f_{\mathrm{j,s}} \cdot g'_{\mathrm{m,i}}\right) & \text{if } \mathbf{SWOPREXT} = 1 \\ g'_{\mathrm{mb,i}} & \text{else} \end{cases} \tag{8.24}$$

$$\mathbf{gds\_i} = \begin{cases} g_{\mathrm{fact}} \cdot g'_{\mathrm{ds,i}} & \text{if } \mathbf{SWOPREXT} = 1 \\ g'_{\mathrm{ds,i}} & \text{else} \end{cases} \tag{8.25}$$

$$\mathbf{gm} = \begin{cases} g_{\mathrm{fact}} \cdot h_{\mathrm{j,s}} \cdot g'_{\mathrm{m}} & \text{if } \mathbf{SWOPREXT} = 1 \\ g'_{\mathrm{m}} & \text{else} \end{cases} \tag{8.26}$$

$$\mathbf{gmb} = \begin{cases} g_{\mathrm{fact}} \cdot \left(g'_{\mathrm{mb}} - f_{\mathrm{j,s}} \cdot g'_{\mathrm{m}}\right) & \text{if } \mathbf{SWOPREXT} = 1 \\ g'_{\mathrm{mb}} & \text{else} \end{cases} \tag{8.27}$$

$$\mathbf{gds} = \begin{cases} g_{\mathrm{fact}} \cdot g'_{\mathrm{ds}} & \text{if } \mathbf{SWOPREXT} = 1 \\ g'_{\mathrm{ds}} & \text{else} \end{cases} \tag{8.28}$$

Parasitic capacitances

$$f_{\mathrm{cx}} = \frac{1}{1 + f_{\mathrm{d}} + f_{\mathrm{s}}} \tag{8.29}$$

$$f_{\mathrm{cd}} = f_{\mathrm{d}} \cdot f_{\mathrm{cx}} \tag{8.30}$$

$$f_{\mathrm{cs}} = f_{\mathrm{s}} \cdot f_{\mathrm{cx}} \tag{8.31}$$

$$C'_{\mathrm{gd,ol}} = \frac{\partial\left(Q_{\mathrm{dov}} + Q_{\mathrm{ofd}}\right)}{\partial V_{\mathrm{GP}}} \tag{8.32}$$

$$\mathbf{cgdol} = \begin{cases} C'_{\mathrm{gd,ol}} \cdot \left(1 - f_{\mathrm{cd}}\right) & \text{if } \mathbf{SWOPREXT} = 1 \\ C'_{\mathrm{gd,ol}} & \text{else} \end{cases} \tag{8.33}$$

$$C'_{\mathrm{gs,ol}} = \frac{\partial(Q_{\mathrm{sov}} + Q_{\mathrm{ofs}})}{\partial V_{\mathrm{GP}}} \tag{8.34}$$

$$\textbf{cgsol} = \begin{cases} C'_{\mathrm{gs,ol}} \cdot (1 - f_{\mathrm{cs}}) & \text{if } \textbf{SWOPREXT} = 1 \\ \\ C'_{\mathrm{gs,ol}} & \text{else} \end{cases} \tag{8.35}$$

$$\textbf{cgbol} = \frac{\partial(Q_{\mathrm{bov}})}{\partial V_{\mathrm{GP}}} \tag{8.36}$$

$$C'_{\mathrm{j,d}} = -\frac{\partial Q_{\mathrm{j,D}}}{\partial V_{\mathrm{DI}}} \tag{8.37}$$

$$\textbf{cjd} = \begin{cases} C'_{\mathrm{j,d}} \cdot (1 - f_{\mathrm{cd}}) & \text{if } \textbf{SWOPREXT} = 1 \\ \\ C'_{\mathrm{j,d}} & \text{else} \end{cases} \tag{8.38}$$

$$C'_{\mathrm{j,s}} = -\frac{\partial Q_{\mathrm{j,S}}}{\partial V_{\mathrm{SI}}} \tag{8.39}$$

$$\textbf{cjs} = \begin{cases} C'_{\mathrm{j,s}} \cdot (1 - f_{\mathrm{cs}}) & \text{if } \textbf{SWOPREXT} = 1 \\ \\ C'_{\mathrm{j,s}} & \text{else} \end{cases} \tag{8.40}$$

Capacitances and transcapacitances

$$C'_{\mathrm{dd,i}} = \frac{\partial Q_{\mathrm{D}}^{(i)}}{\partial V_{\mathrm{DI}}} \tag{8.41}$$

$$C'_{\mathrm{dg,i}} = -\frac{\partial Q_{\mathrm{D}}^{(i)}}{\partial V_{\mathrm{GP}}} \tag{8.42}$$

$$C'_{\mathrm{db,i}} = -\frac{\partial Q_{\mathrm{D}}^{(i)}}{\partial V_{\mathrm{BP}}} \tag{8.43}$$

$$C'_{\mathrm{gd,i}} = -\frac{\partial Q_{\mathrm{G}}^{(i)}}{\partial V_{\mathrm{DI}}} \tag{8.44}$$

$$C'_{\mathrm{gg,i}} = \frac{\partial Q_{\mathrm{G}}^{(i)}}{\partial V_{\mathrm{GP}}} \tag{8.45}$$

$$C'_{\mathrm{gb,i}} = -\frac{\partial Q_{\mathrm{G}}^{(i)}}{\partial V_{\mathrm{BP}}} \tag{8.46}$$

$$C'_{\mathrm{bd,i}} = -\frac{\partial Q_{\mathrm{B}}^{(i)}}{\partial V_{\mathrm{DI}}} \tag{8.47}$$

$$C'_{\mathrm{bg,i}} = -\frac{\partial Q_{\mathrm{B}}^{(i)}}{\partial V_{\mathrm{GP}}} \tag{8.48}$$

$$C'_{\mathrm{bb,i}} = \frac{\partial Q_{\mathrm{B}}^{(i)}}{\partial V_{\mathrm{BP}}} \tag{8.49}$$

$$C'_{\mathrm{dd}} = C'_{\mathrm{dd,i}} + C'_{\mathrm{gd,ol}} + C'_{\mathrm{j,d}} \tag{8.50}$$

$$C'_{\mathrm{dg}} = C_{\mathrm{dg,i}} + C'_{\mathrm{gd,ol}} \tag{8.51}$$

$$C'_{\mathrm{db}} = C'_{\mathrm{db,i}} + C'_{\mathrm{j,d}} \tag{8.52}$$

$$C'_{\mathrm{gd}} = C'_{\mathrm{gd,i}} + C'_{\mathrm{gd,ol}} \tag{8.53}$$

$$C'_{\mathrm{gg}} = C'_{\mathrm{gg,i}} + C'_{\mathrm{gs,ol}} + C'_{\mathrm{gd,ol}} + \mathbf{cgbol} \tag{8.54}$$

$$C'_{\mathrm{gb}} = C'_{\mathrm{gb,i}} + \mathbf{cgbol} \tag{8.55}$$

$$C'_{\mathrm{bd}} = C'_{\mathrm{bd,i}} + C'_{\mathrm{j,d}} \tag{8.56}$$

$$C'_{\mathrm{bg}} = C'_{\mathrm{bg,i}} + \mathbf{cgbol} \tag{8.57}$$

$$C'_{\mathrm{bb}} = C'_{\mathrm{bb,i}} + \mathbf{cgbol} + C'_{\mathrm{j,s}} + C'_{\mathrm{j,d}} \tag{8.58}$$

$$C'_{\mathrm{gs}} = C'_{\mathrm{gg}} - C'_{\mathrm{gd}} - C'_{\mathrm{gb}} \tag{8.59}$$

$$C'_{\mathrm{bs}} = C'_{\mathrm{bb}} - C'_{\mathrm{bd}} - C'_{\mathrm{bg}} \tag{8.60}$$

$$f_{\mathrm{cg}} = f_{\mathrm{cs}} + g'_{\mathrm{m,i}} \cdot \mathbf{RG} \cdot f_{\mathrm{cx}} \tag{8.61}$$

$$Ck_{\mathrm{g}} = C'_{\mathrm{dg}} \cdot f_{\mathrm{cx}} - C'_{\mathrm{bg}} \cdot f_{\mathrm{cs}} + C'_{\mathrm{gg}} \cdot f_{\mathrm{cg}} \tag{8.62}$$

$$Ck_{\mathrm{d}} = C'_{\mathrm{dd}} \cdot f_{\mathrm{cx}} + C'_{\mathrm{bd}} \cdot f_{\mathrm{cs}} + C'_{\mathrm{gd}} \cdot f_{\mathrm{cg}} \tag{8.63}$$

$$Ck_{\mathrm{b}} = C'_{\mathrm{db}} \cdot f_{\mathrm{cx}} + C'_{\mathrm{bb}} \cdot f_{\mathrm{cs}} - C'_{\mathrm{gb}} \cdot f_{\mathrm{cg}} \tag{8.64}$$

$$Ck_{\mathrm{s}} = Ck_{\mathrm{g}} + Ck_{\mathrm{b}} - Ck_{\mathrm{d}} \tag{8.65}$$

$$f_{\mathrm{deld}} = (Ck_{\mathrm{d}} \cdot \mathbf{RDE} - Ck_{\mathrm{s}} \cdot \mathbf{RSE}) \cdot f_{\mathrm{cx}} \tag{8.66}$$

$$f_{\mathrm{delg}} = (C'_{\mathrm{gd}} \cdot \mathbf{RDE} - C'_{\mathrm{gs}} \cdot \mathbf{RSE}) \cdot f_{\mathrm{cx}} \tag{8.67}$$

$$f_{\mathrm{delb}} = (C'_{\mathrm{bd}} \cdot \mathbf{RDE} - C'_{\mathrm{bs}} \cdot \mathbf{RSE}) \cdot f_{\mathrm{cx}} \tag{8.68}$$

$$\mathbf{cdd\_i} = \begin{cases} Ck_{\mathrm{d}} - g'_{\mathrm{ds,i}} \cdot f_{\mathrm{deld}} - \mathbf{cgdol} - \mathbf{cjd} & \text{if } \mathbf{SWOPREXT} = 1 \\ \\ C'_{\mathrm{dd,i}} & \text{else} \end{cases} \tag{8.69}$$

$$\mathbf{cdg\_i} = \begin{cases} Ck_{\mathrm{g}} + g'_{\mathrm{m,i}} \cdot f_{\mathrm{deld}} - \mathbf{cgdol} & \text{if } \mathbf{SWOPREXT} = 1 \\ \\ C'_{\mathrm{dg,i}} & \text{else} \end{cases} \tag{8.70}$$

$$\mathbf{cdb\_i} = \begin{cases} Ck_{\mathrm{b}} + g'_{\mathrm{mb,i}} \cdot f_{\mathrm{deld}} - \mathbf{cjd} & \text{if } \mathbf{SWOPREXT} = 1 \\ \\ C'_{\mathrm{db,i}} & \text{else} \end{cases} \tag{8.71}$$

$$\textbf{cgd\_i} = \begin{cases} C'_{\mathrm{gd}} - g'_{\mathrm{ds,i}} \cdot f_{\mathrm{delg}} - \textbf{cgdol} & \text{if } \textbf{SWOPREXT} = 1 \\ C'_{\mathrm{gd,i}} & \text{else} \end{cases} \tag{8.72}$$

$$\textbf{cgg\_i} = \begin{cases} C'_{\mathrm{gg}} + g'_{\mathrm{m,i}} \cdot f_{\mathrm{delg}} - \textbf{cgsol} - \textbf{cgdol} - \textbf{cgbol} & \text{if } \textbf{SWOPREXT} = 1 \\ C'_{\mathrm{gg,i}} & \text{else} \end{cases} \tag{8.73}$$

$$\textbf{cgb\_i} = \begin{cases} C'_{\mathrm{gb}} - g'_{\mathrm{mb,i}} \cdot f_{\mathrm{delg}} - \textbf{cgbol} & \text{if } \textbf{SWOPREXT} = 1 \\ C'_{\mathrm{gb,i}} & \text{else} \end{cases} \tag{8.74}$$

$$\textbf{cbd\_i} = \begin{cases} C'_{\mathrm{bd}} - g'_{\mathrm{ds,i}} \cdot f_{\mathrm{delb}} - \textbf{cjd} & \text{if } \textbf{SWOPREXT} = 1 \\ C'_{\mathrm{bd,i}} & \text{else} \end{cases} \tag{8.75}$$

$$\textbf{cbg\_i} = \begin{cases} C'_{\mathrm{bg}} - g'_{\mathrm{m,i}} \cdot f_{\mathrm{delb}} - \textbf{cgbol} & \text{if } \textbf{SWOPREXT} = 1 \\ C'_{\mathrm{bg,i}} & \text{else} \end{cases} \tag{8.76}$$

$$\textbf{cbb\_i} = \begin{cases} C'_{\mathrm{bb}} + g'_{\mathrm{mb,i}} \cdot f_{\mathrm{delb}} - \textbf{cgbol} - \textbf{cjs} - \textbf{cjd} & \text{if } \textbf{SWOPREXT} = 1 \\ C'_{\mathrm{bb,i}} & \text{else} \end{cases} \tag{8.77}$$

8.3.2 Noise Sources and Associated FoM

$$\textbf{sfl} = \begin{cases} f_{\mathrm{cx}}^2 \cdot S_{\mathrm{fl}} & \text{if } \textbf{SWOPREXT} = 1 \\ S_{\mathrm{fl}} & \text{else} \end{cases} \tag{8.78}$$

$$f_{\mathrm{g}} = \textbf{RG} \cdot g'_{\mathrm{m,i}} \tag{8.79}$$

$$\textbf{sid} = \begin{cases} f_{\mathrm{cx}}^2 \cdot \left(S_{\mathrm{id}} + f_{\mathrm{s}}^2 \cdot S_{\mathrm{R_S}} + f_{\mathrm{d}}^2 \cdot S_{\mathrm{R_D}} + f_{\mathrm{g}}^2 \cdot S_{\mathrm{R_G}}\right) & \text{if } \textbf{SWOPREXT} = 1 \\ S_{\mathrm{id}} & \text{else} \end{cases} \tag{8.80}$$

$$\omega_{\mathrm{noi}} = 2 \cdot \pi \cdot 10^3 \tag{8.81}$$

$$f_{\mathrm{Sigd}} = C'_{\mathrm{gd}} \cdot \textbf{RDE} \cdot \omega_{\mathrm{noi}} \tag{8.82}$$

$$f_{\mathrm{Sigs}} = C'_{\mathrm{gs}} \cdot \textbf{RSE} \cdot \omega_{\mathrm{noi}} \tag{8.83}$$

$$f_{\mathrm{Sigg}} = C'_{\mathrm{gg}} \cdot \textbf{RG} \cdot \omega_{\mathrm{noi}} \tag{8.84}$$

$$S_{\mathrm{ig,1k}} = \left(\omega_{\mathrm{noi}} \cdot C_{\mathrm{Geff}}\right)^2 \cdot m_{\mathrm{ig}} \tag{8.85}$$

$$S'_{\mathrm{ig}} = \frac{\boldsymbol{N}_{\mathbf{T}} \cdot S_{\mathrm{ig,1k}}}{1 + S_{\mathrm{ig,1k}} \cdot m_{\mathrm{ig}}} \tag{8.86}$$

$$\textbf{sig} = \begin{cases} f_{\mathrm{Sigd}}^2 \cdot S_{\mathrm{R_D}} + f_{\mathrm{Sigs}}^2 \cdot S_{\mathrm{R_S}} + f_{\mathrm{Sigg}}^2 \cdot S_{\mathrm{R_G}} + S'_{\mathrm{ig}} & \text{if } \textbf{SWOPREXT} = 1 \\ \\ S'_{\mathrm{ig}} & \text{else} \end{cases} \tag{8.87}$$

$$\textbf{cigid} = \frac{m_{\mathrm{igid}}}{\sqrt{m_{\mathrm{ig}} \cdot m_{\mathrm{id}}}} \tag{8.88}$$

$$\textbf{sigs} = \begin{cases} f_{\mathrm{cd}}^2 \cdot S_{\mathrm{igs}} & \text{if } \textbf{SWOPREXT} = 1 \\ \\ S_{\mathrm{igs}} & \text{else} \end{cases} \tag{8.89}$$

$$\textbf{sigd} = \begin{cases} f_{\mathrm{cd}}^2 \cdot S_{\mathrm{igd}} & \text{if } \textbf{SWOPREXT} = 1 \\ \\ S_{\mathrm{igd}} & \text{else} \end{cases} \tag{8.90}$$

$$\textbf{sibs} = \begin{cases} f_{\mathrm{cd}}^2 \cdot S_{\mathrm{ibs}} & \text{if } \textbf{SWOPREXT} = 1 \\ \\ S_{\mathrm{ibs}} & \text{else} \end{cases} \tag{8.91}$$

$$\textbf{sibd} = \begin{cases} f_{\mathrm{cd}}^2 \cdot S_{\mathrm{ibd}} & \text{if } \textbf{SWOPREXT} = 1 \\ \\ S_{\mathrm{ibd}} & \text{else} \end{cases} \tag{8.92}$$

8.3.3 Analog FoM

$$\textbf{ft} = \frac{\textbf{gm\_i}}{2 \cdot \pi \cdot (\textbf{cgg\_i} + \textbf{cgsol} + \textbf{cgdol} + \textbf{cgbol})} \tag{8.93}$$

Section 9

History of the model and documentation

9.1 History of the model

April 2005 Release of PSP 100.0 (which includes JUNCAP2 200.0) as part of SiMKit 2.1. A Verilog-A implementation of the PSP-model is made available as well. The PSP-NQS model is released as Verilog-A code only.

August 2005 Release of PSP 100.1 (which includes JUNCAP2 200.1) as part of SiMKit 2.2. Similar to the previous version, a Verilog-A implementation of the PSP-model is made available as well and the PSP-NQS model is released as Verilog-A code only. Focus of this release was mainly on the optimization of the evaluation speed of PSP. Moreover, the PSP implementation has been extended with operating point output (SiMKit-version only).

March 2006 Release of PSP 101.0 (which includes JUNCAP2 200.1) as part of SiMKit 2.3. PSP 101.0 is *not* backward compatible with PSP 100.1. Similar to the previous version, a Verilog-A implementation of the PSP-model is made available as well and the PSP-NQS model is released as Verilog-A code only. Focus of this release was on the implementation of requirements for CMC standardization, especially those which could not preserve backward compatibility.

June 2006 Release of PSP 102.0 (which includes JUNCAP2 200.1) as part of SiMKit 2.3.2. PSP 102.0 is backward compatible with PSP 101.0 in all practical cases, provided a simple transformation to the parameter set is applied (see description below). Similar to the previous version, a Verilog-A implementation of the PSP-model is made available as well and the PSP-NQS model is released as Verilog-A code only. Global parameter sets for PSP 101.0 can be transformed to PSP 102.0 by replacing **DPHIBL** (in 102.0 parameter set) by **DPHIBO** · **DPHIBL** (from 101.0 parameter set). After this transformation, the simulation results of PSP 102.0 are identical to those of PSP 101.0 in all practical situations.

October 2006 Release of PSP 102.1 (which includes JUNCAP2 200.2) as part of SiMKit 2.4. PSP 102.1 is backward compatible with PSP 102.0. SiMKit 2.4 includes a preliminary implementation of the PSP-NQS model. Similar to the previous version, a Verilog-A implementation of the PSP-model is available as well.

October 2007 Release of PSP 102.2 (which includes JUNCAP2 200.3). PSP 102.2 is backward compatible with PSP 102.1. This release provides an express version of JUNCAP2.

April 2008 Release of PSP 102.3 (which includes JUNCAP2 200.3) as part of SiMKit 3.1. PSP 102.3 is backward compatible with PSP 102.2. Focus of this release is on the implementation of asymmetric models for both junction and overlap regions of the drain side.

November 2008 Release of PSP 103.0 (which includes JUNCAP 200.3) as part of SiMKit 3.2. PSP 103.0 is *not* fully backward compatible with PSP 102.3. The main changes are:

- Global, local and binning models are unified. When **SWGEO** $= 1$ (default) global model is used. When **SWGEO** $= 0$ local model is selected. The binning model is invoked if **SWGEO** is set to 2.
- Added non-uniform doping (NUD) model. The model can be invoked on by setting **SWNUD** $= 1$ or 2. When **SWNUD** $= 1$, a separate surface potential calculation is carried out and the NUD model does not affect the CV results. This avoids non-reciprocal capacitances. When **SWNUD** $= 2$, the extra surface potential calculation is skipped and this may result in non-reciprocal capacitances.
  Added related model parameters **GFACNUDO**, **GFACNUDL**, **GFACNUDLEXP**, **GFACNUDW**, **GFACNUDLW**, **VSBNUDO** and **DVSBNUDO** to global, **GFACNUD**, **VSBNUD** and **DVSBNUD** to local and **POGFACNUD**, **PLGFACNUD**, **PWGFACNUD**, **PLWGFACNUD**, **POVSBNUD** and **PODVSBNUD** to binning models.
- Added $V_{\rm th}$-adjustment model for CV. It can be turned on by setting **SWDELVTAC** $= 1$. Note that this requires extra computation of surface potentials. Added related model parameters **FACNEFFACO**, **FACNEFFACL**, **FACNEFFACW**, **FACNEFFACLW**, **DELVTACO**, **DELVTACL**, **DELVTACLEXP**, **DELVTACW** and **DELVTACLW** to global, **FACNEFFAC** and **DELVTAC** to local and **POFACNEFFAC**, **PLFACNEFFAC**, **PWFACNEFFAC**, **PLWFACNEFFAC**, **PODELVTAC**, **PLDELVTAC**, **PWDELVTAC** and **PLWDELVTAC** to binning model.
- Added external diffusion resistances to source and drain. Added instance parameters **NRS** and **NRD**; added model parameters **RSH** to global and binning, **RSE** and **RDE** to local model.
- Modified the geometrical scaling rules of following parameters: **VFB**, **STVFB**, **DPHIB**, **STBET** and **STTHESAT**.
- Modified the binning rule of **BETN**.
- Removed the effect of **FETA** from CV.
- Added local parameter values to OP-output.
- Some minor bug-fixes and implementation changes.

May 2009 Release of PSP 103.1 (which includes JUNCAP 200.3) as part of SiMKit 3.3. The main changes are:

- Added external sheet resistance **RSHD** for drain diffusion (used when **SWJUNASYM** $= 1$)
- Bug-fix and minor implementation change in NUD-model
- Minor bug fix in conditional for SP-calculation of overlap areas.
- Added noise source labeling (vA-code only)

December 2009 Release of PSP 103.1.1 (which includes JUNCAP 200.3) as part of SiMKit 3.4. The main changes are:

- Modified implementation of the asymmetrical junction model to improve simulation speed of verilog-A code.
- Modified implementation of the stand-alone JUNCAP2 model.
- Modified implementation of the MULT-scaling factor.
- Modified implementation of NUD model.
- Minor bug fixes.

July 2010 Release of PSP 103.1.2β as part of SiMKit 3.5. The main changes are:

- Changes in the calculation of the surface-potential in the overlap regions and the calculation of the gate-current. These modifications lead to an 7% simulation speed increase, but leads to some small changes in the overlap-capacitance, gate-current, and GIDL-current w.r.t. the previous version.

December 2012 Release of PSP 103.2.0 (which includes JUNCAP 200.4) as part of SiMKit 4.0.1. The main changes are:

- Changes in the calculation of the surface potential in the overlap regions (see July 2010).
- Introduction of self heating. The self heating version of the model has a fifth terminal (dt) to represent the temperature increase. New parameters: **RTH**, **CTH**, **STRTH** (local model), **RTHO**, **CTHO**, **STRTHO** (global model and binning model).
- Some minor bug-fixes in the calculation of the OP-output.
- Several improvements in the noise-model implementation
  - Fixed sign of correlation coefficient (Verilog-A only).
  - Simplified implementation and better scaled noise amplitude at internal nodes (Verilog-A only).
  - Improved behavior when crossing $V_{\rm ds} = 0$ at high-frequency.
- Scaled junction parameters added to OP-output.
- New parameter **PARAMCHK** to set level of clip warnings (SiMKit only).
- More efficient model evaluation when **MULT** $= 0$ (SiMKit only).

December 2013 Release of PSP 103.3.0 (which includes JUNCAP 200.4) as part of SiMKit 4.2. The main changes are:

- Addition of excess noise, which is important for sub-100-nm channel lengths. This addition is backwards compatible with PSP 103.2. New parameters: **FNTEXC** (local model), **FNTEXCL** (global model), and **POFNTEXC**, **PLFNTEXC**, **PWFNTEXC**, **PLWFNTEXC** (binning model).
- Minor bugfixes.

August 2016 Release of PSP 103.4 (which includes JUNCAP 200.5) as part of SiMKit 4.2. PSP 103.4 is backward compatible with PSP 103.3. The main changes are:

- Addition of edge MOSFET for modeling of subthreshold hump effect. It can be turned on by setting **SWEDGE**=1. New parameters: **VFBEDGE**, **STVFBEDGE**, **DPHIBEDGE**, **NEFFEDGE**, **CTEDGE**, **BETNEDGE**, **STBETEDGE**, **PSCEEDGE**, **PSCEBEDGE**, **PSCEDEDGE**, **CFEDGE**, **CFDEDGE**, **CFBEDGE**, **FNTEDGE**, **NFAEDGE**, **NFBEDGE**, **NFCEDGE**, **EFEDGE** (local model), **WEDGE**, **WEDGEW**, **VFBEDGEO**, **STVFBEDGEO**, **STVFBEDGE**, **STVFBEDGEW**, **STVFBEDGELW**, **DPHIBEDGEO**, **DPHIBEDGEL**, **DPHIBEDGELEXP**, **DPHIBEDGEW**, **DPHIBEDGELW**, **NSUBEDGEO**, **NSUBEDGEL**, **NSUBEDGEW**, **NSUBEDGELW**, **CTEDGEO**, **CTEDGEL**, **CTEDGELEXP**, **FBETEDGE**, **LPEDGE**, **BETEDGEW**, **STBETEDGEO**, **STBETEDGEL**, **STBETEDGEW**, **STBETEDGELW**, **PSCEEDGE**, **PSCEEDGELEXP**, **PSCEEDGEW**, **PSCEBEDGEO**, **PSCEDEDGEO**, **CFEDGEL**, **CFEDGELEXP**, **CFEDGEW**, **CFDEDGEO**, **CFBEDGEO**, **FNTEDGEO**, **NFAEDGELW**, **NFBEDGELW**, **NFCEDGELW**, **EFEDGEO** (global model), and **POVFBEDGE**, **POSTVFBEDGE**, **PLSTVFBEDGE**, **PWSTVFBEDGE**, **PLWSTVFBEDGE**, **PODPHIBEDGE**, **PLDPHIBEDGE**, **PWDPHIBEDGE**, **PLWDPHIBEDGE**, **PONEFFEDGE**, **PLNEFFEDGE**, **PWNEFFEDGE**, **PLWNEFFEDGE**, **POCTEDGE**, **PLCTEDGE**, **PWCTEDGE**, **PLWCTEDGE**, **POBETNEDGE**, **PLBETNEDGE**, **PWBETNEDGE**, **PLWBETNEDGE**,

POSTBETEDGE,**PLSTBETEDGE**, **PWSTBETEDGE**, **PLWSTBETEDGE**, **POPSCEEDGE**, **PLPSCEEDGE**, **PWPSCEEDGE**, **PLWPSCEEDGE**, **POPSCEBEDGE**, **POPSCEDEDGE**, **POCFEDGE**, **PLCFEDGE**, **PWCFEDGE**, **PLWCFEDGE**, **POCFDEDGE**, **POCFBEDGE**, **POFNTEDGE**, **PONFAEDGE**, **PLNFAEDGE**, **PWNFAEDGE**, **PLWNFAEDGE**, **PONFBEDGE**, **PLNFBEDGE**, **PWNFBEDGE**, **PLWNFBEDGE**, **PONFCEDGE**, **PLNFCEDGE**, **PWNFCEDGE**, **PLWNFCEDGE**, **POEFEDGE** (binning model).

- New switch to active/disable the induced gate noise **SWIGN** (default value is 1 for backwards compatibility).
- New parameters for modeling of short channel effects on subthreshold slope:
  - Subthrehold slope degradation for short channel transistors: **PSCE** (local model), **PSCEL**, **PSCELEXP**, **PSCEW** (global model), and **POPSCE**, **PLPSCE**, **PWPSCE**, **PLWPSCE** (binning model).
  - Subthrehold slope dependence with drain voltage: **PSCED** (local model), **PSCEDO** (global model), and **POPSCED** (binning model).
  - Subthrehold slope dependence with bulk voltage: **PSCEB** (local model), **PSCEBO** (global model), and **POPSCEB** (binning model).
- New parameter of JUNCAP model: Coefficient for reverse breakdown current limitation **FREV**.
- Minor bugfixes.

April 2017 Release of PSP 103.5 (which includes JUNCAP 200.5). PSP 103.5 is backward compatible with PSP 103.4. The main changes are:

- Addition of new mobility parameters for Coulomb scattering effect: **THECS**, **STTHECS** (local model), **THECSO**, **STTHECSO** (global model), and **POTHECS**, **POSTTHECS** (binning model).
- Addition of new parameters for quadratic temperature dependence of flatband voltage: **ST2VFB** (local model), **ST2VFBO** (global model), and **POST2VFB** (binning model).

December 2017 Release of PSP 103.6 (which includes JUNCAP 200.5). PSP 103.6 is backward compatible with PSP 103.5. The changes are:

- Induced gate noise: clipped value of migid using the correlation factor c_igid.
- Thermal noise of edge transistor: bug fix to avoid possible division by zero during the calculation of redge.
- Improvement of gm/Id in weak inversion: new model of interface states.
- Addition of new parameter **NSUBEDGELEXP**: exponent for channel length dependence of edge transistor substrate doping.
- Minimum values of calculated local parameters **NOV** and **NOVD** in global mode: now in lines with minimum values of local model parameters.

February 2019 Release of PSP 103.7 and JUNCAP 200.6. PSP 103.7 is backward compatible with PSP 103.6. JUNCAP 200.6 is backwards compatible with JUNCAP 200.5. The changes are:

- Gate leakage currents: additional parameters for overlaps gate leakage currents **GC2OV**, **GC3OV** (local model), **GC2OVO**, **GC3OVO** (global model), and **POCG2OV**, **POCG3OV** (binning model).
- Charge partitioning: new switch parameter **SWQPART** to modify the charge partitioning between the drain and the source.

- Charge model in saturation: by setting **SWQSAT**=1, additional parameters for charge model to improve CV description in saturation **CFAC**, **THESATAC**, **AXAC**, **ALPAC** (local model), **CFACL**, **CFACLEXP**, **CFACW**, **THESATACO**, **THESATACL**, **THESATACLEXP**, **THESATACW**, **THESATACLW**, **KVSATAC**, **AXACO**, **AXACL**, **ALPACL**, **ALPACLEXP**, **ALPACW** (global model), and **POCFAC**, **PLCFAC**, **PWCFAC**, **PLWCFAC**, **POTHESATAC**, **PLTHESATAC**, **PWTHESATAC**, **PLWTHESATAC**, **POAXAC**, **PLAXAC**, **PWAXAC**, **PLWAXAC**, **POALPAC**, **PLALPAC**, **PWALPAC**, **PLWALPAC** (binning model).
- Juncap2: addition of 2 multiplier factors for current **IFACTOR** and charge **CFACTOR**.

July 2020 Release of PSP 103.8. PSP 103.8 is backward compatible with PSP 103.7. JUNCAP 200.6.1 is unchanged for users (minor code cleaning in the Verilog-A code version). The changes of PSP model are:

- Inner fringe charges model: additional parameters **CINR**, **CINRD**, **DVFBINR**, **FCINRDEP**, **FCINRACC**, **AXINR** (local model), **CINRW**, **CINRDW**, **DVFBINRO**, **FCINRDEPO**, **FCINRACCO**, **AXINRO** (global model), and **POCINR**, **PLCINR**,**PWCINR**, **PLWCINR**, **POCINRD**, **PLCINRD**, **PWCINRD**, **PLWCINRD**, **POFCINRDEP**, **POFCINRACC**, **PODVFBINR**, **POAXINR** (binning model).
- Inversion charge of overlaps: additional parameters **FCGOVACC**, **FCGOVACCD**, **CGOVACCG** (local model), **FCGOVACCO**, **FCGOVACCDO**, **CGOVACCGO** (global model), **POFCGOVACC**, **POFCGOVACCD**, **POCGOVACCG** (binning model).
- Modification of gmin implementation in the Verilog-A code.
- Fix on the sign of the flicker noise sources including edge transistor.
- Code cleaning to improve the run-time for the Verilog-A code version.

April 2021 Release of PSP 103.8.1. PSP 103.8.1 is backward compatible with PSP 103.8. The changes of PSP model are:

- Addition of parameters for temperature control: **TRISE**, **DTEMP** and **TREF**.
- Modification of scaling rules of inner fringe charges (physical vs electrical width).
- Somes fixes in the Verilog-A code version.

Release of JUNCAP 200.6.2. JUNCAP 200.6.2 is backwards compatible with JUNCAP 200.6.1. The changes of JUNCAP model are:

- Addition of parameters for temperature control: **TRISE**, **DTEMP** and **TREF**.
- Somes fixes in the Verilog-A code version.

June 2022 Release of PSP 103.8.2. PSP 103.8.2 is backward compatible with PSP 103.8. The changes of PSP model are:

- Addition of flag for fixes: **SWFIX**.
- Somes fixes in the Verilog-A code version.
- Bug fix has been corrected on inner fringe capacitances in accumulation regime.

September 2023 Release of PSP 104.0.0. PSP 104.0.0 is **not** backward compatible with PSP 103.8.x. The changes of PSP model are:

- New DIBL model based on a quasi-Fermi level correction including screening effect in inversion regime.
- Addition of new parameters to improve gm description in saturation regime: **THESATT** (local model), **THESATTO** (global model), **POTHESATT** (binning model).
- Bug-fix on the Cgb-Cbg reciprocity in strong inversion regime when the bias-dependence of interface states model is activated with high value of CTG/CTB parameters.
- New calculation of the drain saturation voltage to improve the drain saturation current of long channel transistors.
- Improvement of S/D symmetry for low value of **AX** parameter thanks to the introduction of a new mathematical function of linear-saturation transition.
- Bug-fix on the source and drain access resistances should be independent to the number of fingers **NF**.
- Removal of the effective doping bias-dependence effect in the surface potential equation and its associated parameters **VNSUB**. **VNSUBO**. **POVNSUB**. **NSLP**, **NSLPO**, **PONSLP**, **DNSUB**, **DNSUBO** and **PODNSUB**.
- New binning equations with "hybrid" approach to mix physical scaling rules with binning rules.
- Revisited DC operating point output variables with 2 new switches to configure the conventions: pmos convention with **SWOPPMOS** and drain configuration with **SWOPDRAIN**. The effects of access gate, drain and source resistances can be included in the calculation of several OP-output quantities using **SWOPREXT**.

9.2 History of the documentation

April 2005 First release of PSP (PSP 100.0) documentation.

August 2005 Documentation updated for PSP 100.1, errors corrected and new items added.

March 2006 Documentation adapted to PSP 101.0. Added more details on noise-model implementation and a full description of the NQS-model.

June 2006 Documentation adapted to PSP 102.0 and some errors corrected.

October 2006 Documentation adapted to PSP 102.1 and some errors corrected.

October 2007 Documentation adapted to PSP 102.2 and some errors corrected.

April 2008 Documentation adapted to PSP 102.3 and some errors corrected.

November 2008 Documentation adapted to PSP 103.0 and some errors corrected.

June 2009 Documentation adapted to PSP 103.1 and some errors corrected.

December 2012 Documentation adapted to PSP 103.2.

December 2013 Documentation adapted to PSP 103.3 and some errors corrected.

August 2016 Documentation adapted to PSP 103.4.

April 2017 Documentation adapted to PSP 103.5.

December 2017 Documentation adapted to PSP 103.6

February 2019 Documentation adapted to PSP 103.7 and JUNCAP 200.6

July 2020 Documentation adapted to PSP 103.8

April 2021 Documentation adapted to PSP 103.8.1

June 2022 Documentation adapted to PSP 103.8.2

September 2023 Documentation adapted to PSP 104.0.0

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Appendix A

Auxiliary Equations

In this Appendix, some auxiliary functions which are used in the model equations are defined.

The MINA-smoothing function:

$$\mathrm{MINA}\left(x,\, y,\, a\right) = \frac{1}{2} \cdot \left[x + y - \sqrt{\left(x - y\right)^2 + a}\right] \tag{A.1}$$

The MAXA-smoothing function:

$$\mathrm{MAXA}\left(x,\, y,\, a\right) = \frac{1}{2} \cdot \left[x + y + \sqrt{\left(x - y\right)^2 + a}\right] \tag{A.2}$$

The MNE- and MXE-smoothing functions:

$$\mathrm{MNE}\left(x,\, y,\, \varepsilon\right) = \frac{2}{A} \left[x + y - \sqrt{\left(x + y\right)^2 - A \cdot xy}\right] \tag{A.3}$$

$$\mathrm{MXE}\left(x,\, y,\, \varepsilon\right) = \frac{2}{A} \left[x + y + \sqrt{\left(x + y\right)^2 - A \cdot xy}\right] \tag{A.4}$$

$$A = 4 - \varepsilon; \qquad \varepsilon \in (0, 1) \tag{A.5}$$

The functions $\chi(y)$, its derivatives, σ_1, and σ_2, which are used in the explicit approximation of surface potential:

$$\chi(y) = \frac{y^2}{2 + y^2} \tag{A.6}$$

$$\chi'(y) = \frac{4y}{(2 + y^2)^2} \tag{A.7}$$

$$\chi''(y) = \frac{8 - 12y^2}{(2 + y^2)^3} \tag{A.8}$$

$$\nu = a + c \tag{A.9}$$

$$\mu_1 = \frac{v^2}{\tau} + \frac{c^2}{2} - a \tag{A.10}$$

$$\sigma_1\left(a,\, c,\, \tau,\, \eta\right) = \frac{a \cdot \nu}{\mu_1 + \left(c^2/3 - a\right) \cdot c \cdot \nu/\mu_1} + \eta \tag{A.11}$$

$$\mu_2 = \frac{v^2}{\tau} + \frac{c^2}{2} - a \cdot b \tag{A.12}$$

$$\sigma_2\left(a,\, b,\, c,\, \tau,\, \eta\right) = \frac{a \cdot \nu}{\mu_2 + \left(c^2/3 - a \cdot b\right) \cdot c \cdot \nu/\mu_2} + \eta \tag{A.13}$$

Appendix B

Layout parameter calculation

In post-layout simulations, various PSP instance parameters should be supplied either manually or by a layout extraction tool. In this appendix, it is shown how these parameters should be calculated.

Note: These equations are *not* part of the PSP model.

B.1 Stress parameters

B.1.1 Layout effects for irregular shapes

For irregular shapes the following effective values for **SA** and **SB** are to be used (see Fig B.1).

$$\frac{1}{\mathbf{SA}_{\text{eff}} + 0.5 \cdot L} = \sum_{i=1}^{n} \frac{\mathbf{SW}_i}{W} \cdot \frac{1}{\mathbf{SA}_i + 0.5 \cdot L} \tag{B.1}$$

$$\frac{1}{\mathbf{SB}_{\text{eff}} + 0.5 \cdot L} = \sum_{i=1}^{n} \frac{\mathbf{SW}_i}{W} \cdot \frac{1}{\mathbf{SB}_i + 0.5 \cdot L} \tag{B.2}$$

B.2 Well proximity effect parameters

The values of the instance parameters **SCA**, **SCB** and **SCC** can be calculated from layout parameters using the equations below.

$$f_{\text{A}}(u) = \frac{\mathbf{SCREF}^2}{u^2} \tag{B.3}$$

$$f_{\text{B}}(u) = \frac{u}{\mathbf{SCREF}} \cdot \exp\left(-10 \cdot \frac{u}{\mathbf{SCREF}}\right) \tag{B.4}$$

$$f_{\text{C}}(u) = \frac{u}{\mathbf{SCREF}} \cdot \exp\left(-20 \cdot \frac{u}{\mathbf{SCREF}}\right) \tag{B.5}$$

$$\begin{aligned} A_{\text{corner}} = &\sum_{i=m+1}^{m+k} \left(\frac{L}{2} \cdot \int_{\text{SCX}_i+\text{SCY}_i}^{\text{SCX}_i+\text{SCY}_i+W} f_{\text{A}}(u)\,\mathrm{d}u \right) \\ &+ \sum_{i=n+1}^{n+k} \left(\frac{W}{2} \cdot \int_{\text{SCX}_i+\text{SCY}_i}^{\text{SCX}_i+\text{SCY}_i+L} f_{\text{A}}(u)\,\mathrm{d}u \right) \end{aligned} \tag{B.6}$$

$$B_{\mathrm{corner}} = \sum_{i=m+1}^{m+k} \left(\frac{L}{2} \cdot \int_{\mathrm{SCX}_i+\mathrm{SCY}_i}^{\mathrm{SCX}_i+\mathrm{SCY}_i+W} f_{\mathrm{B}}(u)\,\mathrm{d}u \right) + \sum_{i=n+1}^{n+k} \left(\frac{W}{2} \cdot \int_{\mathrm{SCX}_i+\mathrm{SCY}_i}^{\mathrm{SCX}_i+\mathrm{SCY}_i+L} f_{\mathrm{B}}(u)\,\mathrm{d}u \right) \tag{B.7}$$

$$C_{\mathrm{corner}} = \sum_{i=m+1}^{m+k} \left(\frac{L}{2} \cdot \int_{\mathrm{SCX}_i+\mathrm{SCY}_i}^{\mathrm{SCX}_i+\mathrm{SCY}_i+W} f_{\mathrm{C}}(u)\,\mathrm{d}u \right) + \sum_{i=n+1}^{n+k} \left(\frac{W}{2} \cdot \int_{\mathrm{SCX}_i+\mathrm{SCY}_i}^{\mathrm{SCX}_i+\mathrm{SCY}_i+L} f_{\mathrm{C}}(u)\,\mathrm{d}u \right) \tag{B.8}$$

$$\mathbf{SCA} = \frac{1}{W \cdot L} \cdot \left[\sum_{i=1}^{n} \left(W_i \cdot \int_{\mathrm{SC}_i}^{\mathrm{SC}_i+L} f_{\mathrm{A}}(u)\,\mathrm{d}u \right) + \sum_{i=n+1}^{n+m} \left(L_i \cdot \int_{\mathrm{SC}_i}^{\mathrm{SC}_i+W} f_{\mathrm{A}}(u)\,\mathrm{d}u \right) + A_{\mathrm{corner}} \right] \tag{B.9}$$

$$\mathbf{SCB} = \frac{1}{W \cdot L} \cdot \left[\sum_{i=1}^{n} \left(W_i \cdot \int_{\mathrm{SC}_i}^{\mathrm{SC}_i+L} f_{\mathrm{B}}(u)\,\mathrm{d}u \right) + \sum_{i=n+1}^{n+m} \left(L_i \cdot \int_{\mathrm{SC}_i}^{\mathrm{SC}_i+W} f_{\mathrm{B}}(u)\,\mathrm{d}u \right) + B_{\mathrm{corner}} \right] \tag{B.10}$$

$$\mathbf{SCC} = \frac{1}{W \cdot L} \cdot \left[\sum_{i=1}^{n} \left(W_i \cdot \int_{\mathrm{SC}_i}^{\mathrm{SC}_i+L} f_{\mathrm{C}}(u)\,\mathrm{d}u \right) + \sum_{i=n+1}^{n+m} \left(L_i \cdot \int_{\mathrm{SC}_i}^{\mathrm{SC}_i+W} f_{\mathrm{C}}(u)\,\mathrm{d}u \right) + C_{\mathrm{corner}} \right] \tag{B.11}$$

Here, m and n are the number of projections of the well edge along the length and width of the devices, respectively. Moreover, k is the number of corners selected to account for the ‘corner’ effects.

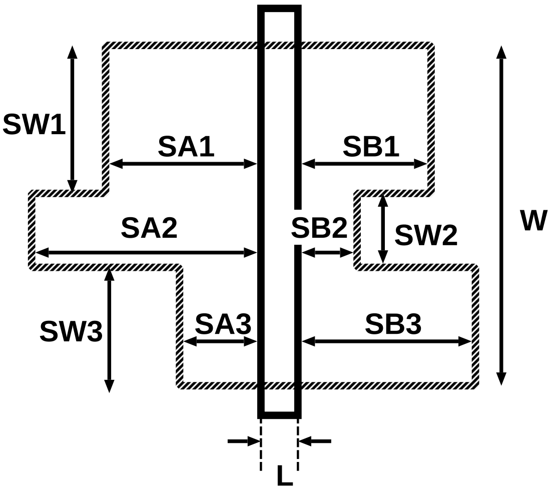

Figure B.1: A typical layout of MOS devices with more instance parameters ($\mathbf{SW}_i$, $\mathbf{SA}_i$ and $\mathbf{SB}_i$) in addition to the traditional L and W.

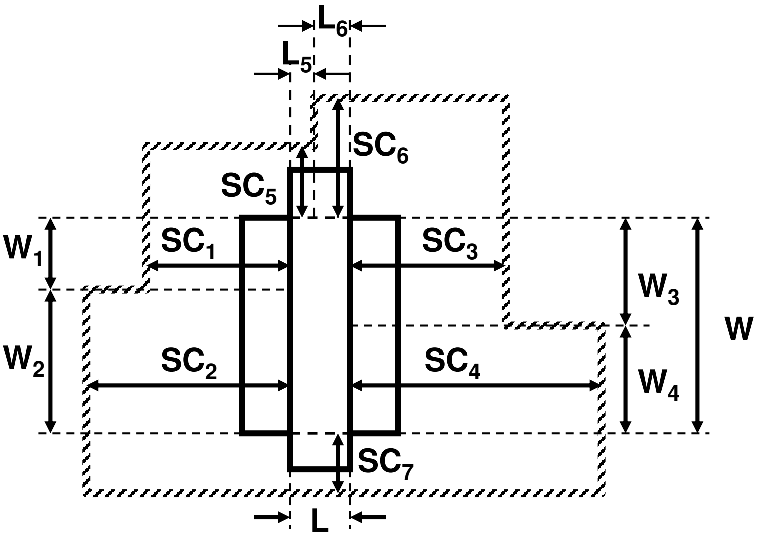

Figure B.2: A typical layout of MOS devices with **WPE** instance parameters

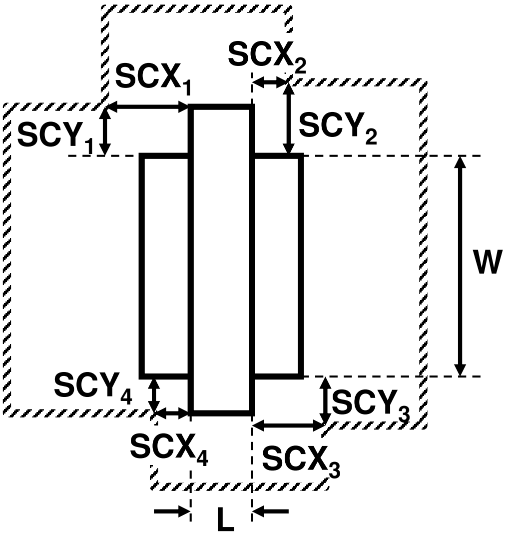

Figure B.3: A layout of MOS devices for corner terms calculation